Pedestrian Safety at Urban Signalised Intersections

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Abstract

Pedestrians are considered as the weakest traffic participants, they are easily involved in traffic accidents with severe consequences, in which more than half occur at urban signalised intersections. Concerning pedestrian safety at urban areas in China, it is much worse than that in the U.S. and European countries, pedestrian fatalities in China are about 20 times higher than those in the U.S. and in Germany under the same motorisation level (the same number of private cars) in 2007. Therefore, it is necessary and urgent to find solutions to improve pedestrian safety in China.

Based on previous studies, it can be concluded that pedestrian safety at signalised intersections is influenced by several clusters of factors, among which behaviour of road users has the most direct impacts. Behaviour of pedestrians and drivers is influenced by internal factors (human factors including demographic and social demographic factors, alcohol etc.) and external factors (background factors, traffic factors, intersection geometry and layout, signal control, traffic education and traffic law enforcement etc.).

Pedestrian safety problems at signalised intersections in China are highlighted through a comparison of pedestrian crossing traffic in Germany and in China mainly based on empirical studies at seven typical signalised intersections in China and eight intersections in Germany. It focuses on pedestrian and driver behaviour and influencing factors on behaviour, such as intersection layout and signal control, traffic education and law enforcement.

Traffic Situation Analysis (TSA) is adopted as the main method for empirical study at intersections out of two reasons: on the one hand, it provides a comprehensive view of traffic situations since complete information of "traffic situations" (e.g. behaviour, traffic conditions, intersection geometry and layout, signal control) are required to obtain; on the other hand, TSA distinguishes interactions (interactions obeying traffic rules and encounters) when pedestrians comply with signals from conflicts due to non-compliance by at least one of the traffic participants. Furthermore, different levels of interactions are distinguished according to the non-compliant behaviour and the executor of a manoeuvre.

The findings of pedestrian safety problems in China can be summarised by:

- Mixed traffic makes the situation at signalised intersections more complicated for pedestrians to handle.
- High rates of pedestrian non-compliance and low rates of driver yielding behaviour as major problems endanger pedestrian safety.
- Traffic planning, design, and operation followed a "vehicle-oriented" notion for a long time, which ignored pedestrian requirements and conversely easily induced improper behaviour of pedestrians and drivers.
- Lack of traffic education is the main reason for low traffic discipline of all road users.
- Traffic laws have some deficiencies and enforcement measures are inefficient and insufficient.

Accordingly, there are two fundamental approaches to improve pedestrian safety at signalised intersections in China, one is to ensure that traffic facilities provide pedestrians with high level of service and the other is to increase road users' compliance with traffic regulations and traffic facilities. Measures of traffic engineering, traffic education and traffic enforcement are sorted and evaluated based on experiences in the U.S., Germany and some other countries.

Concerning particular situations in China, the feasibility and application methods of measures in China are drawn out with comprehensive consideration of efficiency to improve pedestrian safety, influence on the capacity of motorised traffic, and cost. Methodology such as "before-and-after comparison", "treatment-and-control comparison" etc. was employed. The major issues of measures to improve pedestrian safety in China are:

- Traffic education is the basic measure to cultivate a right attitude towards traffic of all road users and provide them with knowledge of safe behaviour. An enhanced school traffic education system should be attached more importance to.
- Pedestrian-friendly facilities are required, especially at sites with high pedestrian volume or high frequency of activities of the elderly, children and handicapped pedestrians. Generally speaking, the requirement of pedestrian-friendly facilities include:
    - reduced vehicle volume and speed,
    - increased visibility for vehicles and pedestrians,
    - ample space for waiting and walking,
    - short crossing distance,
    - signs and signals with high visibility and clear meanings,
    - short waiting time,
    - required minimum green time，
    - sufficient clearance time,
    - reduced conflicts between pedestrians and vehicles,
    - successive crossing without stops, and
    - special consideration for the disabled pedestrians and children.
- Efficient traffic law enforcement is necessary to prevent non-compliance and risky behaviour.

The achievements of the presented research can be summarised as follows:

- analysing characteristics of pedestrian and driver behaviour at signalised intersections,
- finding out influencing factors on pedestrian safety at signalised intersections and their functions,
- pointing out pedestrian safety problems in China, and
- providing a draft of "Guidelines for pedestrian safety at signalised intersections" for China from the aspects of traffic education, traffic law enforcement and traffic engineering, which fills a gap in China and may be also interesting for other countries with similar traffic situations(e.g. India, Vietnam etc.).

Zusammenfassung

Fußgänger werden als die schwächsten Verkehrsteilnehmer angesehen. Schwere Verkehrsunfälle betreffen häufig Fußgänger. Mehr als die Hälfte dieser Unfälle geschehen an signalgeregelten Knotenpunkten innerorts. In China ist die Verkehrssicherheit von Fußgängern in Städten deutlich schlechter als in den USA und in Europa. Die Zahl der in Verkehrsunfällen getöteten Fußgänger war 2007, bezogen auf den gleichen Motorisierungsgrad, ungefähr zwanzigmal so groß wie in den USA und wie in Europa. Deshalb ist es dringend erforderlich zu untersuchen, wie die Verkehrssicherheit von Fußgängern verbessert werden kann.

Vorangehende Untersuchungen zeigen, dass die Verkehrssicherheit von Fußgängern von diversen Faktoren beeinflusst wird, die bestimmten Kategorien zugeordnet werden können. Das Verhalten der Straßennutzer ist dabei die bedeutsamste Kategorie. Grundsätzlich können die Faktoren in interne (sozi-demographische Faktoren, Alkohol etc.) und externe Faktoren (Verkehrsfluss, Knotenpunktgeometrie, Signalprogramm, Verkehrserziehung, Verkehrsüberwachung etc.) eingeteilt werden.

Die Sicherheitsprobleme von Fußgängern an signalgeregelten Knotenpunkten in China wurden in dieser Arbeit durch empirische Vergleiche mit dem Querungsverhalten in Deutschland herausgearbeitet. Zunächst wurden Unfalldaten statistisch ausgewertet. Diese Analyse wurde durch Beobachtungen an sieben typischen signalgeregelten Knotenpunkten in China und acht in Deutschland ergänzt. Die Beobachtungen konzentrierten sich auf das Verhalten von Fußgängern und Autofahrern, sowie die oben genannten Einflussfaktoren.

Aus zwei Gründen wurde für die Untersuchungen die Verkehrssituationsanalyse (VSA) ausgewählt: erstens kann die Verkehrssituation (Verkehrsverhalten, Verkehrsbedingungen, Knotenpunktgeometrie etc.) vollständig abgebildet werden; zweitens unterscheidet diese Methode zwischen Interaktion und Konflikt. Interaktion beschreibt die gegenseitige Beeinflussung von Verkehrsteilnehmern, die sich regelkonform verhalten. Ein Konflikt entsteht, wenn wenigstens ein Verkehrsteilnehmer sich regelwidrig verhält. Interaktionen und Konflikte werden verschiedenen Schweregraden zugeordnet, je nach fehlerhaftem Verhalten und in Abhängigkeit des ein Manöver ausführenden Verkehrsteilnehmers.

Die Ergebnisse der Untersuchungen lassen sich wie folgt zusammenfassen:

- Fußgänger werden durch heterogenen Verkehr stark gefordert.
- Die Verkehrssicherheit leidet deutlich unter regelwidrigem Verhalten von Fußgängern und abbiegenden Autofahrern.
- Lange Zeit waren die Verkehrsplanung, der Entwurf und Betrieb der Verkehrsanlagen auf Kraftfahrzeuge ausgerichtet. Die Bedürfnisse von Fußgängern wurden ignoriert. Die Folge ist regelwidriges Verhalten von Fußgängern und Autofahrern.
- Fehlende Verkehrserziehung ist die Hauptursache für geringe Regeldisziplin aller Verkehrsteilnehmer.
- Die Verkehrsgesetzgebung und die Verkehrsüberwachung sind ineffizient und unzureichend.

Dementsprechend lassen sich zwei grundlegende Ansätze ausmachen, um die Verkehrssicherheit in China zu verbessern: zum einen sollten Verkehrseinrichtungen die Bedürfnisse von Fußgängern ausreichend berücksichtigen, zum anderen muss die Einhaltung der Verkehrsregeln gefördert werden. Um diese Ansätze zu konkretisieren, wurden Maßnahmen der Planung und des Betriebs von Verkehrsanlagen, der Verkehrserziehung sowie der Verkehrsüberwachung strukturiert und bewertet. Erfahrungen aus den USA, Deutschland und weiteren Ländern dienten hierbei als Grundlage.

Maßnahmen für bedeutsame Situationen in China wurden durch Vorher-Nachher-Untersuchungen und Vergleiche mit Kontrollsituationen ausführlich in Hinblick auf ihr Verbesserungspotenzial der Sicherheit, den Einfluss auf die Kapazität des motorisierten Verkehrs und die Kosten untersucht. Als besonders wirkungsvoll sind die folgenden Maßnahmen hervorzuheben:

- Verkehrserziehung ist die Voraussetzung, um bei allen Verkehrsteilnehmer das Bewusstsein für die Risiken im Verkehr und für das richtige Verhalten zu etablieren. Der Verkehrserziehung in der Schule sollte höhere Bedeutung beigemessen werden.
- Verkehrsanlagen sollten fußgängerfreundlich gestaltet werden, insbesondere dort, wo mit vielen mobilitätseingeschränkten Personen, Senioren oder Kindern zu rechnen ist. Folgende Faktoren tragen zur Fußgängerfreundlichkeit bei:
    - geringe Verkehrsstärken und niedrige Geschwindigkeiten
    - gute Sicht für Autofahrer und Fußgänger
    - ausreichend Platz zum Warten und Gehen
    - kurze Furtlängen
    - gut sichtbare und leicht verständliche Verkehrszeichen und Signale
    - kurze Wartezeit
    - erforderliche Mindestfreigabezeit
    - angemessene Räumzeit
    - geringes Konfliktpotenzial zwischen Fußgängern und Fahrzeugen
    - Koordinierung an geteilten Furten
    - besondere Berücksichtigung von Mobilitätseingeschränkten und Kindern
- Effiziente Verkehrsüberwachung ist erforderlich, um regelwidriges und riskantes Verhalten einzudämmen.

Die vorliegende Arbeit liefert

- eine Analyse des Verkehrsverhaltens von Fußgängern und Autofahrern an signalgeregelten Knotenpunkten in China,
- eine Darstellung der Einflussfaktoren auf die Verkehrssicherheit von Fußgängern an signalgeregelten Knotenpunkten in China mit ihren Wirkungszusammenhängen,
- eine Herausarbeitung der Sicherheitsprobleme von Fußgängern in China und
- den Entwurf für eine „Richtlinie für die Verbesserung der Verkehrssicherheit von Fußgängern an signalgeregelten Knotenpunkten", in der Verkehrserziehung, Verkehrsüberwachung sowie Planung und Betrieb von Verkehrsanlagen speziell für China, aber auch für andere Länder mit vergleichbaren Bedingungen, behandelt werden.

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Finally I dedicate this thesis to my beloved parents.

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1. Introduction

1.1 Research background

Pedestrians are recognised as the weakest traffic participants and pedestrian accidents occur frequently in urban areas because pedestrian activities and traffic volumes are greater compared to rural areas. It is claimed that on average, a pedestrian is killed in a motor vehicle crash every 120 minutes and injured every 8 minutes in the U.S. (NHTSA, 2008).

Furthermore, consequences of pedestrian accidents are always severe, an EU report (2003) claims that walking has a 7 to 9 times higher fatality risk per distance travelled than car travel on average. Pedestrian fatalities take a high proportion of traffic accident fatalities, for example, the proportion is 12 %, 14 % and 26 % in the U.S., Germany and China according to the national traffic accident statistics in recent ten years(1998~ 2008).

Traffic accidents have increased largely because of rapid motorisation, especially at the initial stage of a higher motorisation level. The motorisation started to grow around 1998 in China and serious traffic safety problems came out consequently, for example, pedestrian fatalities sharply increased during 1998~2003 (Figure 1). Compared with other highly motorised countries, such as Germany and the U.S., pedestrian safety is much worse in China. The statistical data showed that pedestrian fatalities per 100,000 motorised vehicles in China is about 18 times higher than those in Germany and the U.S. in 2007 (Figure 2).

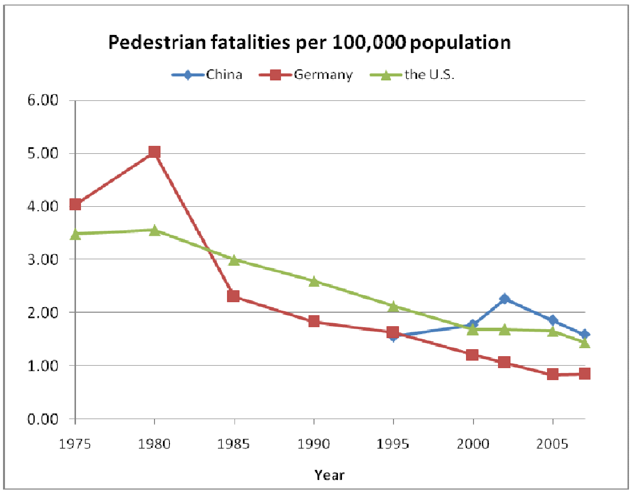


Figure 1: Pedestrian fatalities per 100,000 population

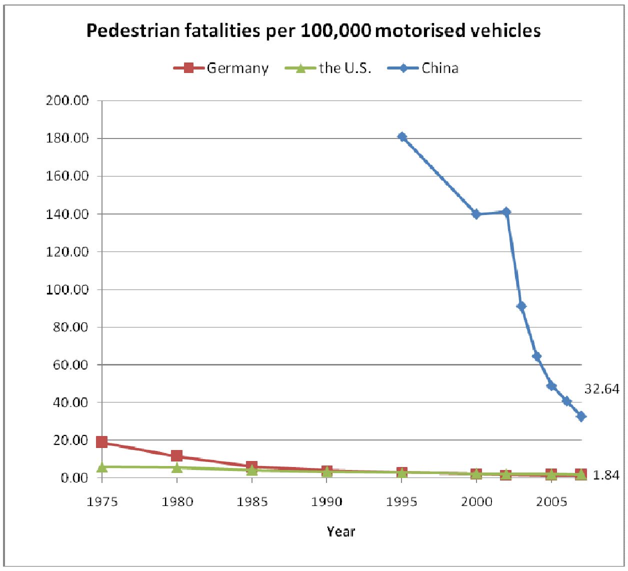


Figure 2: Pedestrian fatalities per 100,000 motorised vehicles

However, it is claimed that the majority of pedestrian accidents with injuries occurred at intersections (Lane, 1996). On the one hand, traffic loads are higher and traffic situations are more complicated at intersections than at mid-blocks, which increases pedestrians' exposure to accidents; on the other hand, pedestrians easily lose their right-of-way at intersections and are often involved in conflicts with motorised vehicles and bicycles.

1.2 Research motivation

As it can be seen in Figure 1 and Figure 2 that pedestrian fatalities started to reduce in the U.S. and Germany around in 1985 and have been keeping in a low level in recent twenty years. The improvement of pedestrian safety can be possibly attributed to the great efforts of three "E"s (Engineering, Education and Enforcement). Programs of traffic education and law enforcement have been carried out and traffic engineering has given particular considerations on pedestrians.

National and local traffic laws and regulations, guidelines and recommendations have taken pedestrian traffic into consideration, for example, in Germany, consideration for pedestrian crossing traffic at signalised intersections is mainly included in the following national laws and guidelines:

- Traffic law: Straßenverkehrs-Ordnung (StVO)
- Capacity manual: Handbuch für die Bemessung von Straßenverkehrsanlagen (HBS , 2001)
- Guidelines for layout design: Richtlinien für die Anlage von Stadtstraßen (RASt , 2006)
- Guidelines for signals: Richtlinien für Lichtsignalanlagen (RilSA ,1976, 1992, 2010)
- Recommendations on pedestrian facilities: Empfehlungen Für Fußgängerverkehrsanlagen (EFA, 2002)

The old "vehicle oriented" notion of traffic engineering concerns only on motorised traffic and aims to increase vehicular capacity as much as possible while neglecting pedestrian requirements, therefore, widened intersections and long cycle times result in high pedestrian non-compliance and lead a vicious cycle (Figure 3). Instead, a new notion called "human centred" has been widely adopted nowadays in Germany and in the U.S., which takes all road users into consideration and attaches more importance to vulnerable traffic participants such as pedestrians.

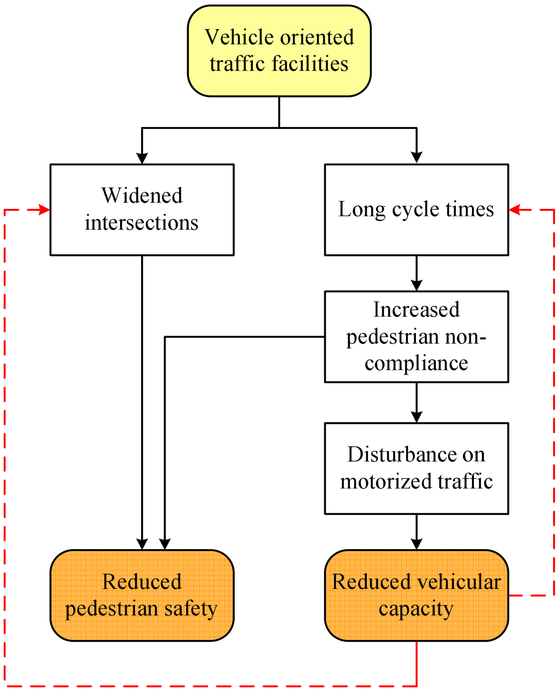


Figure 3: A vicious cycle resulted from vehicle-oriented traffic facilities

However, insufficient attention has been given to pedestrians in China until now, numerous deficiencies of traffic laws and guidelines exist and the vehicle-oriented notion is still adopted, which may result in a further deterioration of pedestrian safety. Therefore, it is urgent to find out effective solutions to solve the problem.

Nevertheless, due to different characteristics of road user behaviour in different areas, the existing guidelines in foreign countries can't be used directly in China. It is helpful to take advanced countries like Germany as a good example and learn useful experiences, meanwhile, targeted studies on pedestrians in China are also required in order to seek efficient and feasible measures with high acceptance by road users.

1.3 Research goals and objectives

The goal of this research is to find out solutions to provide pedestrians with better service at signalised intersections in China, especially to improve pedestrian safety. The goal can be divided into following three objectives:

Objective 1: To find out influencing factors on pedestrian safety at signalised intersections;

Research questions include:

- 1-1: How to evaluate pedestrian safety at signalised intersections?
- 1-2: How do pedestrians and drivers behave at signalised intersections and what are influencing factors on their behaviour?
- 1-3: What is the relationship between road user behaviour and pedestrian safety?
- 1-4: What are other influencing factors on pedestrian safety at signalised intersections and how do they work?

Objective 2: To find out pedestrian safety problems at signalised intersections in China;

Research questions include:

- 2-1: What is the current situation of pedestrian safety at signalised intersections in China?
- 2-2: What are special behaviour characteristics of pedestrians and drivers at signalised intersections in China?
- 2-3: What are the current practices of traffic engineering, education and law enforcement in China and are they reasonable?

Objective 3: To find out efficient and feasible three “E”-solutions to improve pedestrian safety at signalised intersections in China.

Research questions include:

- 3-1: What are possible measures to improve pedestrian safety at signalised intersections and how do they work?
- 3-2: Which measures are efficient and feasible for China and how to apply them?

1.4 Research procedure

The research procedure is shown in the work packages (Figure 4).

WP1	Review of pedestrian safety and influencing factors at signalised intersections
WP2	Identify pedestrian safety problems at signalised intersections in China
WP3	Find out solutions to improve pedestrian safety at signalised intersections in China
WP4	Draft of “Guidelines for pedestrian safety at signalised intersections”
WP5	Conclusions and outlook

Figure 4: Work packages of the research

WP1 is to build a framework of pedestrian safety at signalised intersections, the outcome includes influencing factors on pedestrian safety and suitable methods for this research, which is the basis for further work packages. Empirical studies are carried out in WP2 and WP3, in **WP2,** problems of pedestrian crossing traffic at signalised intersections in China are highlighted through a comparison analysis between China and Germany, **WP3** focuses on finding out targeted measures to solve problems concluded from WP2. **WP4** is to summarise results of WP2 and WP3 in a form of "draft of guidelines", which helps to guide practice. In **WP5**, the whole research is summarised and some research questions are raised for future studies.

More detailed tasks of WP1, WP2, WP3 and methodologies used for each task are listed in Table 1.

Table 1: Tasks and methodologies

WP	tasks	methodologies
1	analysis of general characteristics of pedestrian and driver behaviour at signalised intersections and influencing factors	literature review
	review of different approaches to evaluate pedestrian safety	literature review, comparison analysis
	analysis of influencing factors on pedestrian safety	literature review, systematic analysis
2	comparison of pedestrian accidents in China and in Germany	accident analysis, literature review, statistical analysis of accident data
	comparison of pedestrian and driver behaviour in China and in Germany	video recording, traffic situation analysis, comparison analysis
	comparison of traffic engineering of crossings (layout design and signal control) in China and in Germany	field investigation, video recording, comparison analysis
	comparison of traffic education and law enforcement in China and in Germany	literature review
3	analysis of measures of traffic engineering (layout design and signal control)	literature review, comparison analysis, systematic analysis
	analysis of measures of traffic education and enforcement	literature review, systematic analysis

1.5 Outline of the thesis

In Chapter 2, pedestrian characteristics and behaviour of pedestrians and drivers at signalised intersections are analysed, in relate to WP1 and research questions 1-2, 1-3.

In Chapter 3, three methods evaluating pedestrian safety are reviewed and compared; Clusters of factors influencing pedestrian safety are concluded in relate to WP1 and research questions 1-1, 1-4.

In Chapter 4, a comparison of pedestrian crossing traffic at signalised intersections in Germany and in China is carried out from aspects of statistical analysis of pedestrian accidents, pedestrian and driver behaviour, traffic engineering practices including layout design and signal control of intersections, traffic education and law enforcement. Pedestrian safety problems at signalised intersections in China and relevant reasons are concluded in relate to WP2 and the research questions 2-1, 2-2, 2-3.

In Chapter 5, measures of traffic engineering, traffic education and law enforcement are sought and their efficiency and feasibility to apply in China are analysed, in relate to WP3 and the research questions3-1, 3-2 .

In Chapter 6, a "guideline of pedestrian safety at signalised intersections" is drafted as a summary of results form Chapter 4 and Chapter 5.

Chapter 7 is a summary of the whole research, including achievement, limitations and outlook for future studies.

The relationship among outline, research questions and work packages is shown in Figure 5.

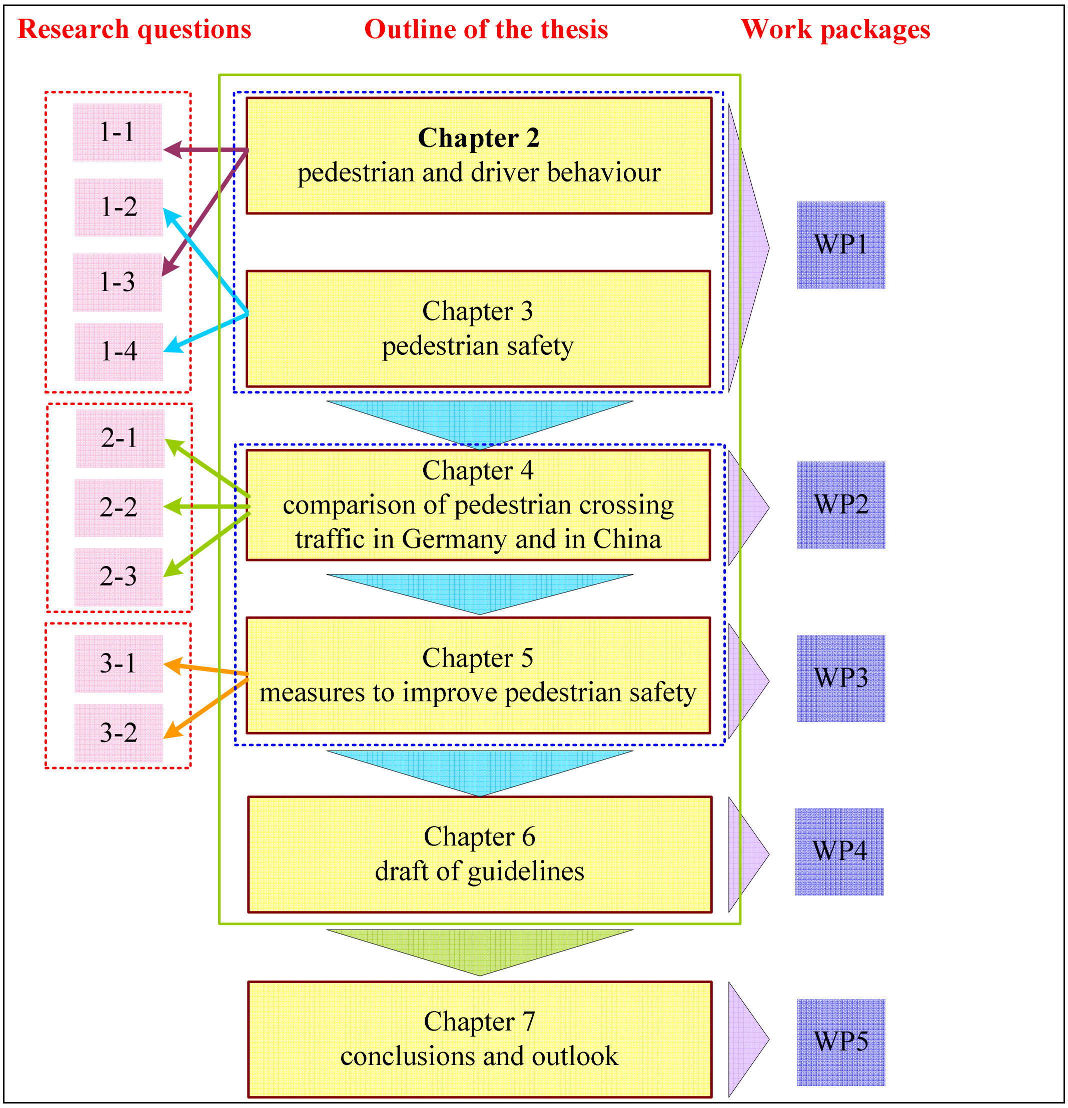


Figure 5: Relationship among outline, research questions and work packages

2. Pedestrian and driver behaviour

2.1 Introduction

2.1.1 Chapter outline

This chapter mainly deals with pedestrian and driver behaviour at signalised intersections.

Firstly, general characteristics of pedestrians is presented in Section 2.1.2, especially particular characteristics of the most vulnerable groups (children younger than 10, the elderly older than 65).

Section 2.1.3 introduces different forms of pedestrian crossing facilities, as well as pedestrian preference of crossing facilities at different locations.

Section 2.2 focuses on pedestrian behaviour at signalised intersections. Pedestrian crossing behaviour can be described in two periods, before crossing and during crossing (Section 2.2.1). Section 2.2.2 detailed pedestrian crossing behaviour into different types and pedestrian non-compliance with signals is recognised as the most risky behaviour, relevant influencing factors are reviewed based on previous studies. Besides, pedestrian non-compliance is explained from a psychological point view by employing behaviour models of "Health Belief Model (HBM)" and "Theory of Planned Behaviour (TPB)".

Driver behaviour towards pedestrians also plays an important role on pedestrian safety at intersections, in Section 2.3, reasons for drivers' failing to yield to pedestrians are also discussed.

2.1.2 General characteristics of pedestrians

The definition of "pedestrian" includes persons travelling on foot as well as those using some appliance or object to help them fulfill that action or to accompany them in fulfilling it; this definition includes pushing a pram, wheelchair, bicycle or moped (not riding) (OECD, 1997).

General characteristics of pedestrians can be concluded as follows:

- Vulnerability: Pedestrian accidents happen frequently, particularly inside of urban areas, and the severity is considerably high. According to the EU data of 15 countries from 1991~2004, pedestrian fatalities takes 32% of all traffic fatalities inside urban areas, while 16% in all areas(including inside and outside urban areas);
- Flexibility: Pedestrian movement patterns including route decision, speeds, manoeuvres etc. vary from different pedestrians under different conditions, and the pedestrians' logic differs from the driver's logic and often is not in line with the designer's logic (Nee and Hallenbeck, 2003). Meanwhile, the demand of "conformity" makes pedestrian prone to be influenced by others.
- Ample space requirement: Pedestrians require ample space when waiting and walking. HCM (2000) recommends that a total area of 0.3 m2 is needed for a pedestrian standing, and a body buffer zone of 0.8 m2 for walking. The minimum width that serves two pedestrians walking together or passing each other is 1.8 m. More space may be required, such as 2.7–3.9 m, to accommodate situations where three or more people are walking abreast. More space is needed for a wheelchair user, a person on crutches and a sight-impaired person using the cane technique (FHWA, 2005).
- Negative attitudes toward regulations: Pedestrian jaywalking and signal violation is quite common all over the world and their wrong behaviour is seldom corrected (Andree, 2007).
- Tendency to move straight and avoid detours: Pedestrians tend to cross following "the

desired line" (a direct connection of the origin and destination), shown in Figure 6.

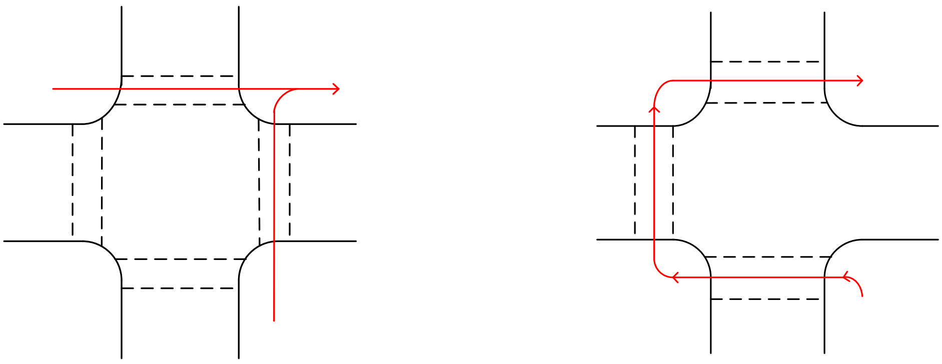


Figure 6: Advantageous and disadvantageous crossings at intersections (source: EFA, 2002)

Among all pedestrians, the children (younger than 10) and the elderly (older than 65) are recognised widely as the most vulnerable groups and a report of FHWA (2005) lists the particular characteristics of them as follows:

The children (10-):

They often have problems with risk perception and attention that make them more vulnerable. Children's comprehension of safety is poorly formulated, and their understanding of critical behaviour is not well developed. The following factors appear to contribute to the child pedestrian problems:

- Their small stature makes it difficult for them to see and evaluate the entire traffic situation correctly.
- They have limited information processing in peripheral vision and poorer visual acuity until about 10.
- They have difficulty distributing their attention and are therefore easily preoccupied or distracted.
- They have difficulty discriminating between right and left.
- They have difficulty in correctly perceiving the direction of sound and the speed of vehicles.
- They have a poor understanding of the use of traffic control devices and crosswalks.
- They have difficulty in judging distances of cars and when a safe gap occurs between vehicles.
- They tend to believe that adults will always be kind to them, so drivers will be able to stop instantly if they are in danger.

The elderly (65+)

In general, the elderly do not behave as irrationally as many children and young adults do, but are more law abiding and may in fact be too trusting of traffic signals and of drivers. They are more likely to be involved in crashes than younger pedestrians due to problems in information processing, judgment and physical constraints to accurately assess the traffic situation, for example:

- Vision is affected in older people by decreased acuity and visual field, loss of contrast sensitivity, and slower horizontal eye movement.
- They often have difficulty with balance and postural stability, resulting in slower walking

speeds and increased chances for tripping.

- Selective attention mechanisms and multitasking skills become less effective with age, so older people may have difficulty locating task-relevant information in a complex environment.
- They have difficulty in assessing the speed of approaching vehicles, thus misjudging when it is safe to cross the road.
- They have slower reaction times and decision-making skills.
- Those with arthritis may have restricted head and neck mobility as well as difficulty walking.
- There is reduced agility for those who use canes or crutches for assistance.

2.1.3 Pedestrian crossing facilities

Pedestrian crossing facilities can be classified into two basic types, one is grade-separated crossing facility such as pedestrian bridges and tunnels, the other is at-grade crossing facility including signalised crossing (with/without pedestrian push button) and unsignalised crossings, for example, zebra crossings with pedestrian priority established in Germany. In UK, signalised crossings are classified into three categories, which are Pelican crossing (with pedestrian push button), Puffin crossing (with push button and other pedestrian detectors) and Toucan crossing (with push button and other detectors) where pedestrians and bicycles are jointly signalised (Davies, 1999).

Pedestrian signals are basic elements of pedestrian crossings at signalised intersections. Generally speaking, pedestrian signal indications should consist of the following three parts:

- Red: pedestrians shall not enter the roadway in the direction of the signal indication;
- Green: pedestrians are permitted to cross the roadway in the direction of the signal direction);
- Signal indication of pedestrian clearance time: pedestrians shall not start to cross the roadway in the direction of the signal indication, but that any pedestrian who has already started to cross on Green shall proceed out of the travelled way.

The signal indications and meanings of Red and Green for pedestrians are nearly the same all over the world, in the U.S., messages are also displayed, “WALK” has the same meaning with Green and Constant “DON'T WALK” has the same meaning with Red. However, there are various signal indications of pedestrian clearance time in different areas. For example, the first several seconds of Red are used for pedestrian clearance in most cities in Germany depending on the clearance distance; Yellow in Düsseldorf; a Flashing hand or Flashing “DON'T WALK” in the U.S. and Flashing Green in many cities in China.

Pedestrians tend to cross the road when it suits them, in terms of convenience and saving time rather than thinking of potential safety implications (Daff et al, 1991; Osborn, 1997; Sisiopiku and Akin, 2003), therefore, it is evident that the origin and destination of the pedestrian are the most influential factors of crossing location decision. Pedestrians would cross from their present positions rather than from a designed crossings if:

- visibility is good (Bernhoft, 2008);
- accepted gap is available (TRL, 2001; Bernhoft, 2008);
- using designated crossings would take too long (TRL, 2001);
- they want to shorten waiting time, a French investigation showed that 64% of the pedestrians stay less than 4 seconds on the sidewalk before starting to cross outside designated crossings (de la Sablière, 1988).

Therefore, unsignalised midblock crossings are the treatment of preference to pedestrians, 83% said so in the investigation of Sisiopiku and Akin (2003). However, designated crossings are thought to be safe and convenient when they are on-route (TRL, 2001), and proper traffic control can further encourage pedestrian to cross at designated locations (Sisiopiku and Akin, 2003). Also it is found that designated crossings and signalised intersections were high priority issues for the elderly, since they had problems to perceive when a gap is sufficient for their crossing (Bernhoft, 2008).

2.2 Pedestrian behaviour

2.2.1 Introduction

Available studies on pedestrian behaviour date from 1960s in Europe. Surely pedestrian behaviour has changed more or less in the past half century because most of the relevant situations have changed, such as the motorisation level, the demographic structure, technology of traffic engineering, traffic education etc.

Generally, pedestrian crossing behaviour at signalised intersections can be described in two periods: "before crossing" and "during crossing".

Before crossing

It is related to the period before pedestrians enter the crossing, either from curb sides or from refuge islands in the middle. It is a period for pedestrians to make decisions, such as "where to cross" and "wait or walk when the signal is red". However, to make a crossing decision at signalised intersections is a complex task:

- At first, a pedestrian starts to make a decision since he has seen the pedestrian signal in a certain distance before he arrives at the crossing, for example, if he sees the signal indication of clearance time, he may speed up or change a route. Furthermore, the "original decision-making point" and the decisions are various from each other.
- Secondly, when pedestrian signal is Red, a pedestrian may have to decide "walk or wait". He has to observe and update traffic situation around and make judgements (Ariane, 2007).

Pedestrian signal violation is the dominant form of non-compliance at signalised intersections during this period. Besides, pedestrians "crossing outside the designed crossings" is the other form of non-compliance, and it is known that when pedestrians cross the road near to a crossing (within 50 m), but not actually on the crossing, collision risk is increased by a factor of four (e.g. Older and Grayson, 1976; Grayson, 1987; Preston, 1989).

During crossing

Pedestrian crossing speeds and manoeuvres are important issues to describe pedestrian behaviour during crossing.

On the base of a large quantity of investigations, 1.0-1.5 m/s is widely agreed as the average crossing speed. However, pedestrian speeds are various from different demographic characteristics in various conditions, such as land use, day period, intersection geometry and layout, group or individual crossing etc. (e.g. Bennett, 2001; Hamed, 2001; Zhao, 2003).

Pedestrian speeds can represent pedestrian safety perception to a certain extent. Retzko and Häckelmann (1977) found that walking speeds depended on the size of risk pedestrians intended to take, the greater the risk, the higher is the walking speed. When there are conflicts, pedestrians walk faster or run (Malkhamah, 1999).

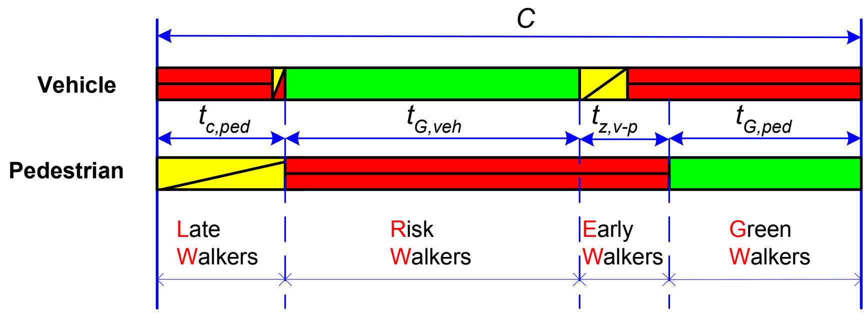
Furthermore, pedestrian speeds change when they take manoeuvres, either on Green or Red to avoid collisions with vehicles. A manoeuvre can be a change of moving speed, for example, pedestrians stop or run, and the speed increases when manoeuvre becomes stronger. Besides, a manoeuvre can also be a change of direction, such as pedestrians withdraw or change routes.

2.2.2 Pedestrian non-compliance

2.2.2.1 Types of pedestrian crossing behaviour

Pedestrian crossing behaviour can be classified into several types according to their compliance /non-compliance with signals. For example:

(1) Androsch (1975) and Häckelmann (1976) classified pedestrian crossing behaviour into four types according to the time when pedestrians enter the street, which are "green walkers (GW)", "late walkers (LW)", "risk walkers (RW)" and "early walkers (EW)" (Figure 7).



Note:

C: cycle length **$t_{G,veh}$**: vehicle green time **$t_{G,ped}$**: pedestrian green time
$t_{c,\ ped}$: pedestrian clearance time
$t_{z,v\text{-}p}$: intergreen time between vehicle green and pedestrian green

Figure 7: Types of pedestrian crossing behaviour (GW, LW, RW, EW) (adapted from Androsch, 1975)

(2) Liu (2000) characterized pedestrian crossing behaviour by using two categories: law-obeying ones and opportunistic ones. Opportunistic ones look for appropriate gaps between vehicles to cross during red time and decide whether to violate traffic signals depending on the states of some external factors (like policeman nearby or not, vehicle flow and other pedestrian behaviour).

(3) According to Oxley (1997), there are non-interactive crossers and interactive crossers. Non-interactive crossers represent pedestrians crossing on Green, they don't have interactions with vehicles and won't stop; interactive crossers include pedestrians who are appealed more willing to cross with closer moving traffic, they are prepared to pause, stop in the middle, change their crossing speeds.

Considering the three classification methods mentioned above, the types of pedestrian crossing behaviour proposed by Androsch (1975) and Häckelmann (1976) contain more detailed information than the other two, a general concept of "crossing on Red" is taken place by "LW, RW and EW", which describes crossing behaviour under different signal displays and periods. Meanwhile, the definition of "non-interactive crossers" proposed by Oxley (1997) is contradictory with the reality, since pedestrians crossing on Green also have to take interactions if permissive turning vehicles fail to yield to them. As a conclusion, the concept of "GW, LW, RW, EW" is adopted in the empirical study in this research.

2.2.2.2 Influencing factors on pedestrian non-compliance

Influencing factors on pedestrian non-compliance, mostly on pedestrian signal violation are sorted into following six groups, in which human factors are internal factors and the other five groups belong to external factors.

Human factors

Quantitative studies underlined a strong relationship between pedestrian crossing behaviour and demographic characteristics, especially age and gender factors. For example,

- Females are more likely to comply with signals than males (e.g. Yagil, 2000; Daff et al., 1991).
- Young men are three times more likely to cross on Red than average (e.g. Daff et al., 1991; Preston, 1986; Garder, 1989). Older pedestrians (typically 65+) are more likely to comply with signals than are younger pedestrians (Daff et al., 1991).
- Male children are more likely to cross without waiting for Green than females, and crossing on Red is found to increase with age during adolescence. Almost 30% of adolescents (aged 11-16 years) often or very often crossing without waiting for Green (Elliott et al., 2003).

Pedestrians with mobility impairments take longer time to cross a road (Reading et al., 1995; Austin et al., 1997) and they may be more likely to comply with signals. Mobility impairment means any aspect that impairs manoeuvre ability, increases crossing time, or affects perceptual/judgement skills that are necessary to cross a road safely, defined by Martin (2006).

Some socio-demographic factors influence pedestrian behaviour as well, such as education level, income level, religion, number of children in household, crossing frequency, previous accident involvement, driving experiences, license ownership etc. (Hamed, 2001; Diaz, 2002).

However, pedestrian psychological factors play a very important role on pedestrian non-compliance, such as pedestrian attitudes towards traffic, social norms, etc. (cf. Section 2.2.2.3). Pedestrians are more likely to violate rules when they are in a hurry, for example, if they are hurrying to work or important appointments, or trying to catch a bus that is about to leave, it’s quite possible that they don’t use crossings, challenging the right-of-way, and violating signals (NTCRP, 2008).

Background factors

Background factors basically include area size, land use, weather, time etc. For instance, Garder (1989) pointed out that town size is one of the greatest influence factors, the larger the city, the greater is the number of red-walkers. Investigation in China found that more pedestrians cross on Red under inclement weather, for example, when it is too hot or too cold.

Traffic factors

Traffic volume has significant impacts on pedestrian crossing behaviour, a negative correlation between signal violation and vehicle volume was concluded (Barker et al., 1991; Craddock, 1992), which means when traffic volume is high, the tendency for pedestrians to cross on Red decreases (Zegeer, 1985; Garder, 1989; Daff et al., 1991; Yagil, 2000). On the contrary, when traffic volume is low, accepted gaps are available, so that pedestrians have more chances to cross on Red (Preston, 1986; Asaba, 1998).

In HCM (2000), critical gap is defined as “the time in seconds below which a pedestrian will not attempt to begin crossing the street. If the available gap is greater than the critical gap, it is assumed that the pedestrian will cross.” The available gap pedestrians accept is called an accepted gap, otherwise it is a rejected gap. Gaps are normally resulted from unsaturated traffic flow or intergreen time between two stages.

An OECD Road research group surveyed accepted gaps in 1970s, a gap of 10.5 seconds was accepted by all observed pedestrians, 4.5 seconds was accepted by half and 1.5 seconds was only accepted by 15% pedestrians. An Indian study suggested that few pedestrians would cross at gaps less than 2 seconds, while most would accept a gap of at least 8 seconds (Das et al., 2005). Studies in China carried out by Zhao (2003) showed that the average accepted gap was 5.79 seconds, and the values were larger when back vehicles are large.

Brewer (2006) pointed out that the accepted gap length increases as crossing distance increases, meanwhile, pedestrians don’t always wait to cross the street when all lanes are completely clear, rather they anticipate that the lanes will be clear as they cross. In another word, a “rolling gap” is used by pedestrians when crossing multi-lane streets.

Besides volume of conflicting traffic, the volume of permissive turning vehicles also influences the proportion of red-walking (Garder, 1989), because if turning vehicles fail to yield to pedestrians, pedestrians would like to cross on Red to compensate their lost time. Pedestrian volume is influential as well, a group of pedestrian violation is more often seen due to the pedestrian psychology of “conformity” (Yagil, 2000).

Intersection geometry and layout factors

Road width and existence of refuge islands are important factors, pedestrians more tend to violate signals at crossings where are easy to cross. For example, small intersections with few lanes or with short crossing distances are normally related to high violation rate (Garder, 1989). The presence of a refuge island increases red-walking by approximately 5% (Garder, 1989) and the violation proportion is higher when pedestrians start from refuge islands than from curb sides (Hamed, 2001; Das et al., 2001).

Transit stops nearby is another reason for pedestrian signal violation, it is often seen that passengers take risks to cross on Red to catch buses (Chu, 2004).

Signal control factors

- Fixed-time control and traffic actuated control

Traffic-actuated control can provide for green time abortion and therefore an earlier beginning of the pedestrian green time (RilSA, 2003). Along with the reduction of pedestrian waiting time, pedestrian non-compliance will also reduce. Austin and Martin (1996) concluded that vehicle actuation could increase the proportion of the cycle available to pedestrians and reduce the level of pedestrian non-compliance.

- Fulfillment of pedestrian requests

Pedestrian requests can be fulfilled by manually pedestrian push button or automatic pedestrian detectors. However, low utilization of pedestrian push button and too long response time lead to higher violation rate. For example, pedestrian behaviour at 64 intersection approaches equipped with pedestrian push buttons in southeastern Michigan was observed, only 51% of pedestrians used the push button, and the signal violation rate reached 66% (Zegeer, 1984).

Automatic pedestrian detectors, which can (1) detect waiting pedestrians; (2) cancel the signal call if the pedestrian leaves the signal before crossing; and (3) extends the crossing time for pedestrians who need extra time while crossing, is reported helpful to reduce proportion of pedestrians crossing on Red (Crabtree , 2002).

- Cycle length and pedestrian red time

Pedestrians are sensitive to waiting time (Andree, 2007), they are feeling more and more impatient along with the increasing waiting time. Asaba and Saito (1998) claimed that a period of 21~28 seconds started to provoke a feeling of impatience. When pedestrian waiting time exceeds their threshold of waiting time, the likelihood of pedestrian non-compliance will increase sharply. A correlation between pedestrian average waiting time and likelihood of pedestrian non-compliance suggested in HCM (2000) is shown in Table 2.

Table 2: Correlation between pedestrian average waiting time and likelihood of pedestrian non-compliance (HCM, 2000)

LOS	pedestrian average waiting time $t_w=r^2/2C$ (s)	likelihood of pedestrian non-compliance
A	<10	low
B	10~20	-
C	20~30	moderate
D	30~40	-
E	40~60	high
F	>60	very high

Since pedestrian average waiting time(t_w) is related to cycle length and pedestrian red time, it has been agreed that shorter cycle times lead to better pedestrian compliance (Reading et al, 1995; Keegan, 2003; Catchpole, 2003). Studies in Aachen(Germany)(1990) showed that signalisations that increased cycle length and pedestrian red time were likely to provoke pedestrian violation, such as “exclusive pedestrian phase”, “separated signal control of turning vehicles”; on the contrary, signalisations reducing pedestrian red time such as “two times pedestrian green time in one cycle” and “green wave for pedestrians” were helpful to reduce pedestrian non-compliance.

However, Garder (1989) pointed out the opposite idea of “the waiting time for green turned out to have very little influence at signalised intersections”. Actually, pedestrian crossing psychology and behaviour is different when crossing at mid blocks (without any crossing facilities) and signalised intersections.

- o At mid blocks pedestrians have to judge situations and make crossing decisions by themselves, they take a risk of failing to cross if traffic volume is too high. In order to “succeed in crossing”, pedestrians may start to accept small gaps after a certain period of waiting, or even force vehicles to decelerate or to stop. The average waiting time is supposed to be the threshold of pedestrian waiting time by former researchers (e.g. Rouphail, 1984).
- o While crossing at signalised crossings, it is no doubt that signal control will ensure pedestrian right-of-way, the question is how long pedestrians have to wait. When accepted gaps appear, pedestrians may seize such opportunities in order to “save time”. Long waiting time at empty street is the most possible situation provoking signal violation, and pedestrians are easily to overestimate their waiting time in front of the road with low traffic volume (Asaba, 1998).

Accordingly, it can be affirmed that long waiting time resulted from long cycle length and long pedestrian red time has negative effect on pedestrian compliance, the longer pedestrians have to wait, the more likely they cross against the signal, but it is hard to determine whether and when pedestrian waiting time is a dominant factor. More general is, waiting time doesn’t function alone, but plays a role of “trigger” together with other factors, the most important one is available gaps.

- Acceptance of signals and signalisation

Signals and signalisation lacking of pedestrian understanding and acceptance contribute to pedestrian non-compliance directly. For example, studies in the U.S. estimated that only 39% of the population understood the meaning of the flashing hand (Lord et al., 1998). Countdown signals have been proved to provide pedestrians with useful information, so that proportion of pedestrian signal violation can be reduced. For example, the proportion of pedestrians crossing on Red reduced from 21% to 16.7% in Hamburg (Germany) after the countdown signal displaying remaining red time was installed (Celikkan et al., 2008).

With reference to signalisation, for example, pedestrian may cross on Red if they see parallel vehicles are still being released (Andree, 2007); progressive signalisation at successive crossings can arouse following misunderstanding,"…who first stop because the signal on the refuge shows red, maybe tempted to violate Red as oncoming pedestrians are still given Green" (RilSA, 2003).

Traffic education and law enforcement factors

Training for safe crossing is an efficient way to decrease pedestrian non-compliance (Thomson, 1997). An TRL report considered that the first main way to influence road user behaviour is via road safety education (Martin, 2006). A review of trials (mostly in children) by Duperrex et al.(2005) found that pedestrian safety education can improve children's road safety knowledge and their observed road crossing behaviour, but may need to be repeated at regular intervals.

Roberts (1997) noted that one possible reason for pedestrians in the UK are more likely to ignore traffic signs and signals is that there is no legal requirement in the UK to obey pedestrian signals, whereas in many other European countries (e.g. Germany, Sweden, Netherlands and Belgium) there is. Studies in China (e.g. Liu, 2000; Li, 2007) showed that when policemen are nearby, the violation rate is lower.

2.2.2.3 Psychological models of pedestrian behaviour

Behavioural models such as "Health Belief Model (HBM)" and "Theory of Planned Behaviour (TPB)" are used to explain pedestrian non-compliance from a psychological point of view.

Health belief model (HBM)

"Health Belief Model" (HBM) is a psychological model that attempts to explain and predict health behaviour (behaviour related certain threat to health) (Rosenstock et al., 1988). It contains three elements which are "background", "perception" and "actions", as shown in Figure 8. In Table 3, elements of HBM applied to describe pedestrian crossing behaviour are explained. The perceived benefits play a very important role, since it has been widely recognised that the main reason behind the lack of compliance with pedestrian signals is that "most pedestrians felt impatient when a red traffic light forced them to wait while no cars were passing" (Daff et al., 1991; Sisiopiku, 2003; Yang, 2005, 2006). In another word, the perceived benefits of saving time overwhelm perceptions of threat when pedestrians tend to violate the signal.

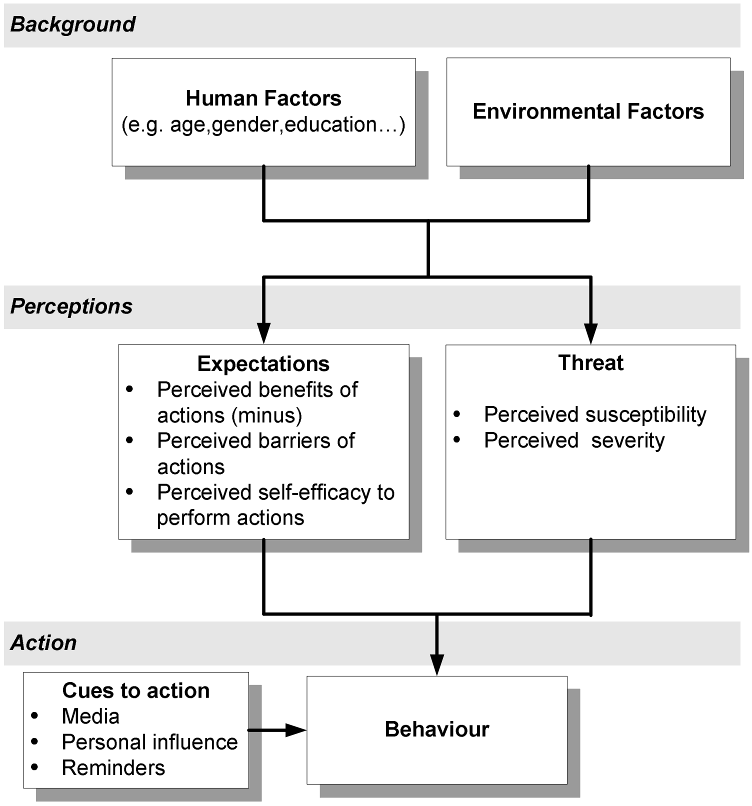


Figure 8: Framework of HBM (adapted from Rosenstock et al., 1988)

Table 3: Application of HBM on pedestrian crossing behaviour (adapted from Yagil, 2000)

concept		application on pedestrian crossing behaviour
background	human factors	- age , gender, impairment - experience of driving - previous traffic accidents involved - education level - familiarity of the location - alcohol - social pressure etc.
	environment factors	- time and weather - intersection geometry and layout design - traffic conditions - signal control - behaviour of other pedestrians etc.
perception	perceived susceptibility	possibility to be involved in a collision
	perceived severity	level of dangers of possible collision
	perceived benefits (minus)	- saving time - preventing boredom / inconvenience etc.
	perceived barriers	- collision endangers life - annoying drivers etc.
	self-efficacy	traffic education
actions	cues to action	- traffic law enforcement (e.g. police presence) - warrant signs etc.

Theory of Planned Behaviour (TPB)

Theory of Planned Behaviour (TPB) predicts deliberate behaviour, which postulates three conceptually independent determinants of intention: attitude towards the behaviour, subjective norm and perceived behavioural control (Figure 9). As a general rule, the more favourable the attitude and subjective norm with respect to a behaviour, and the greater the perceived behavioural control, the stronger should be an individual's intention to perform the behaviour under consideration (Ajzen, 1991).

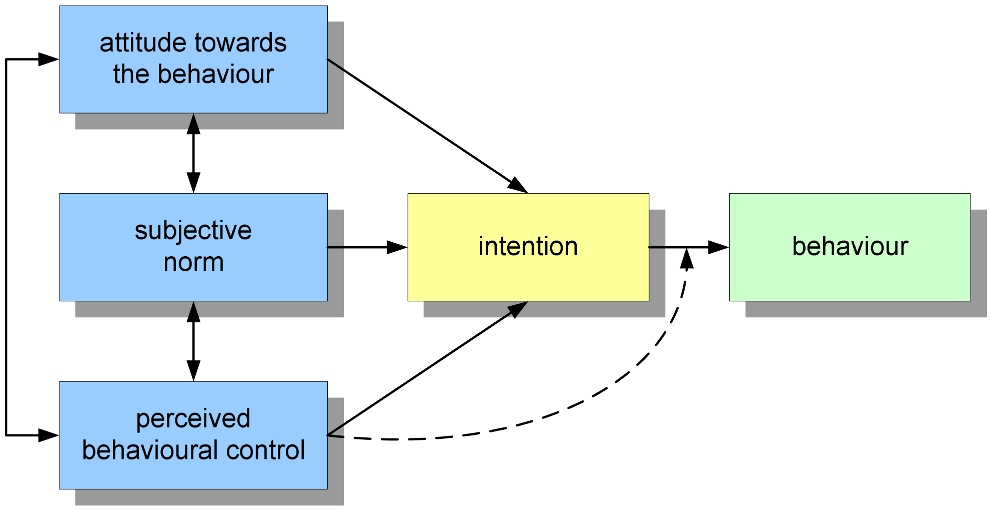


Figure 9: Framework of TPB (adapted from Ajzen,1991)

TPB can explain pedestrian non-compliance in the following points:

- Attitude towards the behaviour: Pedestrians' attitude towards crossing on Red, partly based on evaluation of likely consequences and benefits, e.g. "Can it help me to save time or catch the bus if I cross on Red?", "Will I involve in a collision, if yes, how serious will it be? " etc.
- Subjective norm: Pedestrians' belief in laws and their senses of obligation to obey traffic laws, e.g. "Must I obey the signal?"
- Perceived behavioural control, referring to the perceived ease or difficulty to cross on Red, which depends on the presence factors that may facilitate or impede, similar to "background factors" listed in Table 3.

Nearly all studies confirmed that demographic characteristics, especially age and gender influenced the above three aspects significantly (Evans and Norman, 1998; Yagil, 2000; Diaz, 2002). Attitude is approved to be the main factor affecting pedestrian behaviour, especially among men (Yagil, 2000; Diaz, 2002); perceived behavioural control is one of the key points contributing to final decisions, for example, the "conformity" (or "peer pressure") affects pedestrian behaviour significantly, especially common among women (Yagil, 2000). Pedestrians are less likely to cross if others were waiting (Dannick, 1973; Yagil, 2000), vice versa, once an appropriate gap has been identified, the first pedestrian to cross will be followed by other pedestrians (Yang, 2006).

However, some studies found that the TPB model was poor to predict pedestrian behaviour, because it was considered that the decision of whether to cross on Red is in most cases a result of reaction to a number of factors occurring at the time of crossing, which is more influenced by external factors than by intentions (e.g. Marcal, 1999).

2.3 Driver behaviour

The most important driver behaviour towards pedestrians is "permissive turning vehicles yielding to pedestrians ".

According to traffic laws and regulations, turning drivers should yield to pedestrians who cross on Green, whereas in reality, it differs from areas to areas. It was observed that drivers changed their behaviour in the presence of pedestrians, for example, the mean and standard deviation of accepted gap increased, turning time increased (Rouphail, 1998), a greater reduction in speed occurred when the number of pedestrians was greater than one (Katz et al., 1975). While in contrast, Thompson et al. (1985) found no differences in speed when pedestrians were present in England, the drivers did not even change their paths (i.e. moving further away from the curb).

There are several reasons for drivers' failing to yield to pedestrians:

- Drivers have low traffic discipline, e.g. in China, the turning vehicles seldom give way to pedestrians at crossings, especially to individual pedestrian or small groups, sometimes vehicles may be forced to decelerate or stop when meeting a large group of pedestrians (Zhao, 2003).
- Visibility reasons
    - Drivers have difficulties estimating the possible path of a pedestrian in motion (Stewart, 1991), especially with a high speed (Banerjee et al, 2004).
    - Single or a few crossing pedestrians are easily visually neglected by drivers, "About three quarters of traffic conflicts between pedestrians and left-turning vehicles involved only one pedestrian, and only one quarter of conflicts occurred when a group of pedestrians were crossing" (Lord, 1994).
    - Improper location of crossings can arouse visibility problems. For example, if the crossing is too far back shifted, turning vehicles won't expect pedestrians' existence and they already start with high speeds (Andree, 2007).
    - The driving work load is the greatest for left-turning movements (Harms, 1991; Hancock, 1990; Lord, 1997). The alertness of pedestrians will be reduced if too many through lanes have to be passed or the traffic condition is too complicated (Andree, 2007).

Actually, driver behaviour can be affected by interventions, such as signs to prompt drivers to stop for pedestrians (Van Houten et al., 1992), auxiliary signals to warn drivers of pedestrians, and measures of education and law enforcement as well.

2.4 Conclusions

General characteristics of pedestrians, pedestrian behaviour at signalised intersections and influencing factors, as well as driver behaviour towards pedestrians have been discussed in this chapter.

Pedestrian non-compliance (especially signal violation) is the most significant behaviour at signalised intersections, and "permissive turning vehicles yielding to pedestrians" is the most important driver behaviour towards pedestrians.

Behaviour of pedestrians and drivers is influenced by both internal factors (i.e. human factors) and external factors, mainly include background factors, traffic volume, intersection geometry and layout, signal control, traffic education and law enforcement etc. These factors influence behaviour directly or indirectly via influencing the motivation (Figure 10).

For example, pedestrians are more prone to cross against signals at empty streets with short crossing distance, since the perceived benefits such as saving time overwhelm perceptions of threat; permissive turning vehicles fail to yield to pedestrians either because of poor visibility resulted from improper geometry design or due to improper attitudes towards pedestrians.

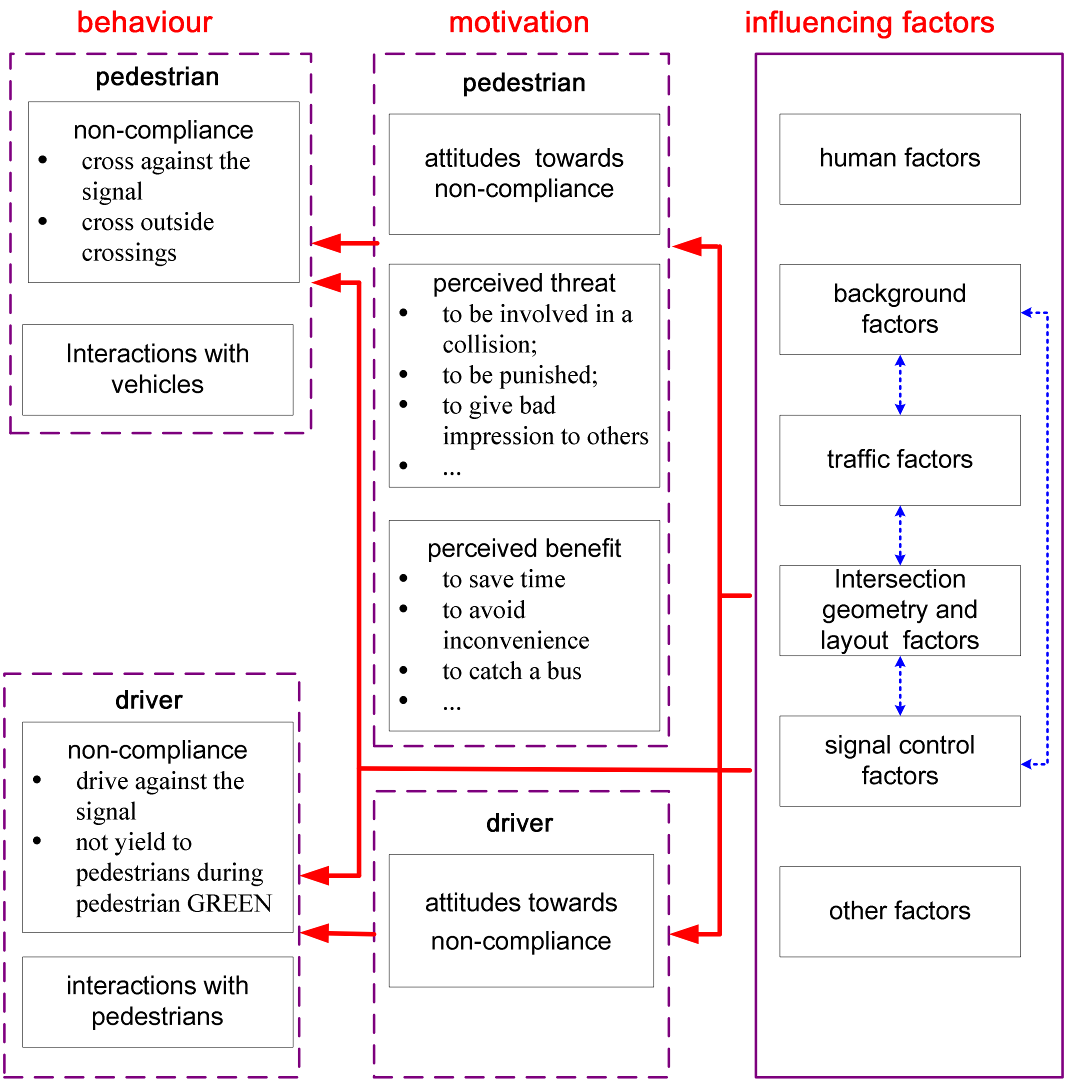


Figure 10: Correlation among behaviour, motivation and influencing factors

3. Pedestrian safety at signalised intersections

3.1 Introduction

Considering the special characteristics of pedestrians, several qualitative performance measures have been proposed as "attractiveness, comfort, convenience, safety, security, system coherence, and system continuity" by Sarkar (1993) and Khisty (1994), among which "safety" is considered as the most important measure related to pedestrian crossing traffic at intersections.

In this chapter, three methods of traffic safety evaluation including accident analysis (Section 3.1), traffic conflict technique (TCT) (Section 3.2) and traffic situation analysis (TSA) (Section 3.3) are explained from the aspects of basic ideas and drawbacks of each method and their applications on pedestrian traffic at signalised intersections. A comparison of the three methods is made in Section 3.4 to determine suitable methods to evaluating pedestrian safety at signalised intersections.

Meanwhile, based on previous studies on pedestrian safety, the influencing factors on pedestrian safety are sorted into groups and the correlation among factors is explained in Section 3.5.

3.2 Pedestrian accident analysis

3.2.1 Overview

3.2.1.1 Pedestrian accident analysis in Germany

Accident analysis is the most classical method to evaluate traffic safety. The analysis of objective accident data of intersections can help traffic engineers in the following aspects:

- find out existing problems at intersections directly;
- recognise and extract important factors affecting safety from statistical analysis;
- establish regression models to predict number of accidents in other sites or in the future.

However, the depth and accuracy of accident analysis is determined mostly by the quality of registered accident data and its availability. Regarding the accident data registration and analysis system, Germany has set a good example.

In general, complete accident analysis in Germany is carried out in three levels: macroscopic, mesoscopic and microscopic level (Figure 11).

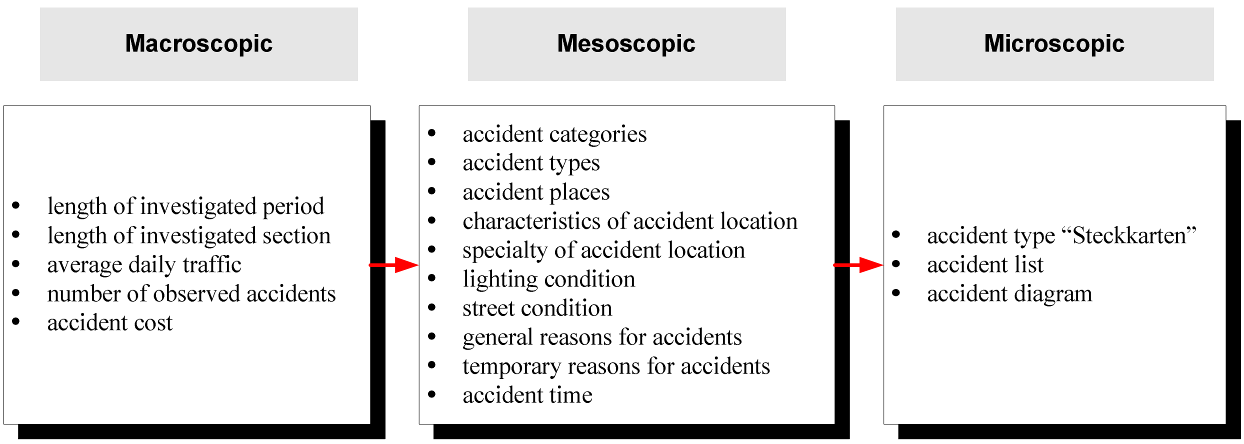


Figure 11: Three levels of accidents analysis in Germany (adapted from Bachmann, 2008)

The EUSka (Elektronische Unfalltypen-Steckkarte), an electronic map of accident types, including the classification of accident data and the analysis procedures for local accident investigations has been developed and replaced paper maps, which helps to analyse accidents more systematically and easily. For example, in Figure 12, a location distribution of pedestrian accidents can be clearly seen that helps traffic engineers to focus on accident black spots.

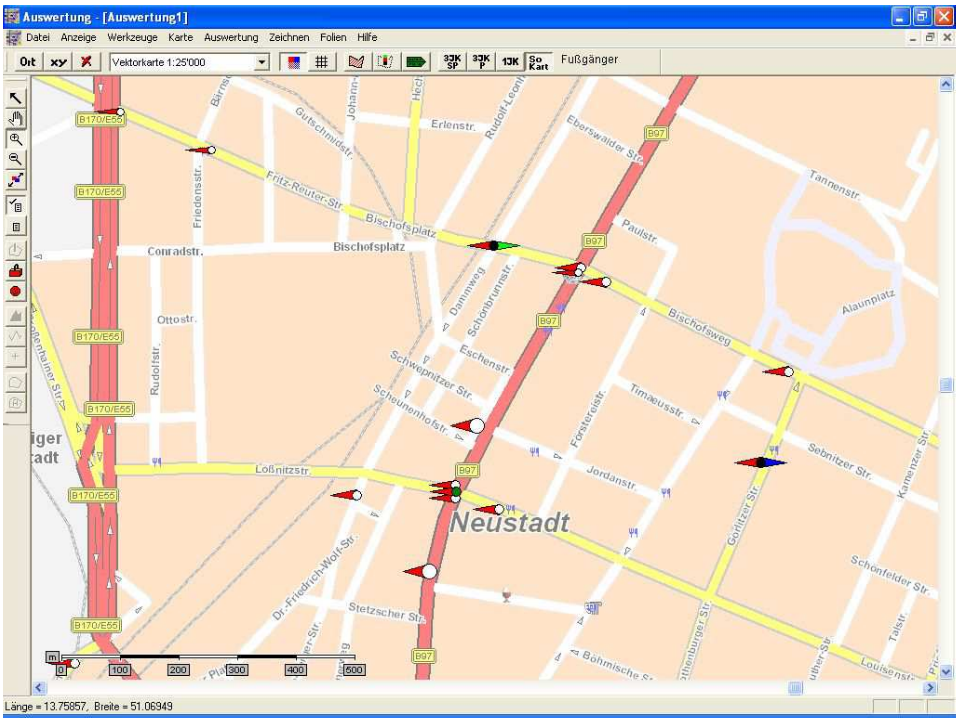


Figure 12: Example of EUSka displaying pedestrian accidents (source: PTV, 2009)

Microscopic level is more suitable for studying pedestrian accident analysis at signalised intersections, since valuable information can be acquired mainly from accident lists and accident diagrams.

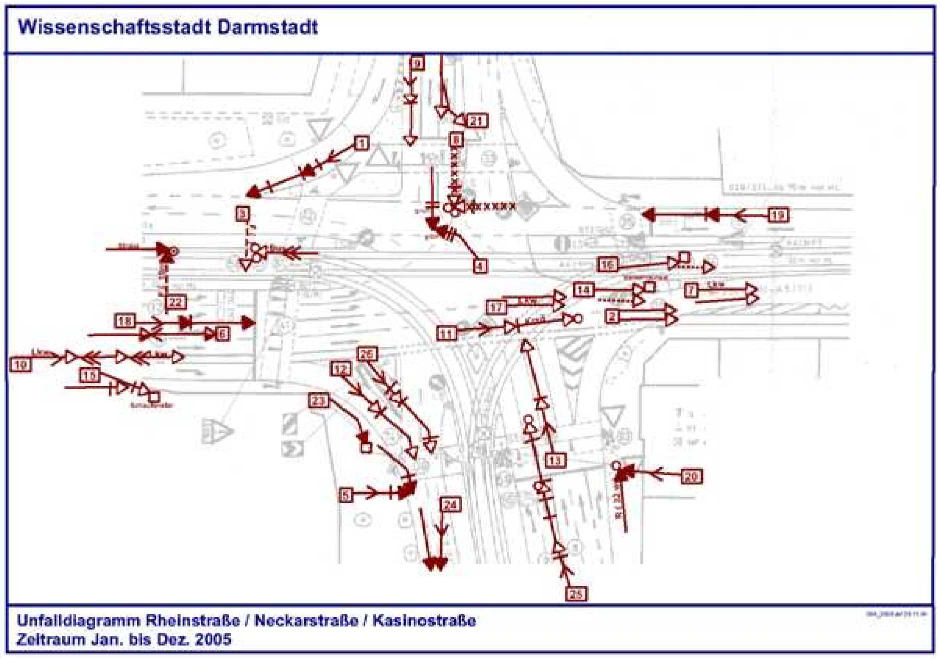


Figure 13: Accident diagram at Rheinstraße-Neckarstraße in Darmstadt
(source: Straßenverkehrsamt, Darmstadt, 2005)

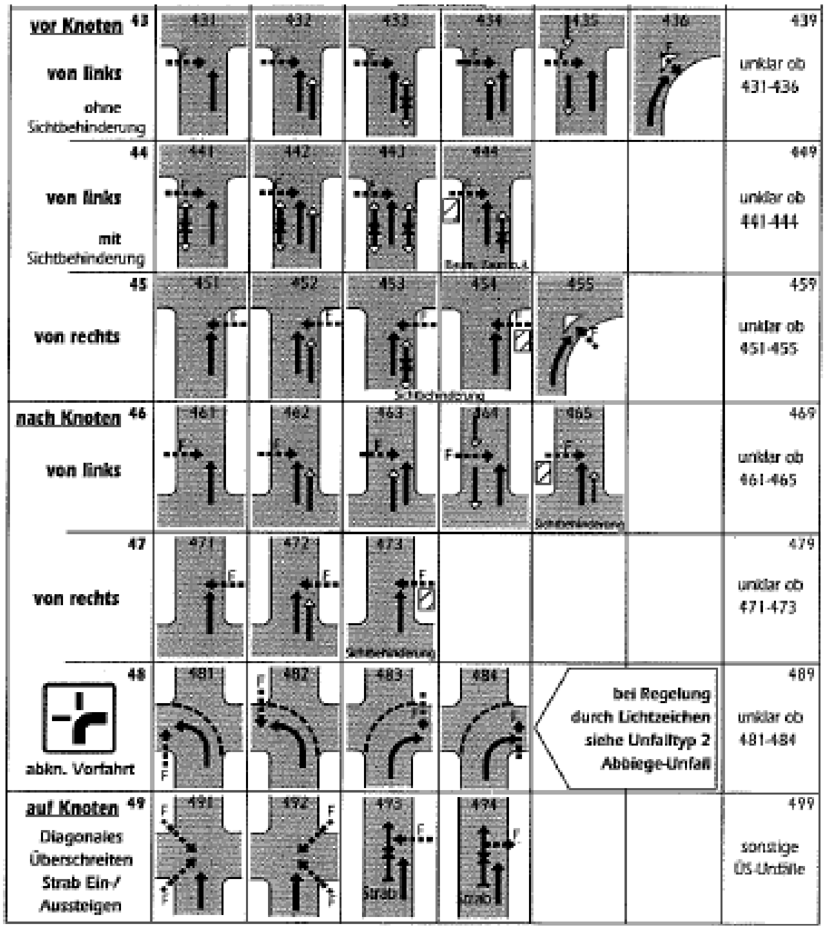
An accident diagram (Figure 13) takes the intersection layout plan as the background, regulated symbols are used to describe accidents happened at the intersection in one year normally. Following information can be acquired with reference to pedestrian accidents:

- exact location of pedestrian accidents
- lighting and pavement conditions
- age of involved pedestrians
- pedestrian crossed on Red or not
- type of involved vehicles (passenger car /heavy vehicle/bus/tram)
- severity of pedestrian accidents (fatality/injury)

An accident list contains general information about background conditions, road and traffic conditions, layout and signal control conditions of the intersection, take accident database of Darmstadt for example, it contains following information:

- names and grades of intersecting roads
- intersection location in the road network
- reconstructed or not
- land use
- traffic related facilities in a vicinity of the intersection (such as train station, hotel, etc)
- trams or busses passing the intersection
- tram stations or bus stops nearby the intersection
- speed limitation of intersecting roads
- general description of pedestrian and cycle traffic (existence/volume is high or low)
- signal control strategy (within the green wave or not)
- transit signal priority
- red light monitoring
- signal for sight-handicapped
- information about traffic signal controller

Generally, urban traffic accidents are classified into seven main types according to “Merkblatt für die Auswertung von Straßenverkehrsunfällen” (FGSV, 1998), among which “accidents related with turning traffic (type 2)” and “street crossing accidents (type 4)” are more related to pedestrian accidents. The main types are classified into several sub-types, for example, regarding one of the main accident types named “street crossing accidents” (type 2), it is classified into several subtypes basically according to the location of accidents(in front , behind or inside of the intersection) and crossing directions of pedestrians(from left or from right), shown in Figure 14. Complete sub-types with reference to pedestrian accidents can be found in Appendix A.



In front of the intersection
pedestrians from left without visibility problems

pedestrians from left with visibility problems

pedestrians from right

Behind the intersection
pedestrians from left

pedestrians from right

with special sign regulating right-of-way

Inside the intersection

Figure 14: Pedestrian street crossing accidents (Type 2)
(source: "Merkblatt für die Auswertung von Straßenverkehrsunfällen", FGSV, 1998)

Detailed accident analysis of Darmstadt (Germany) (2001~2005) is carried out following the methods mentioned above, see Appendix A.

3.2.1.2 Accident and risk

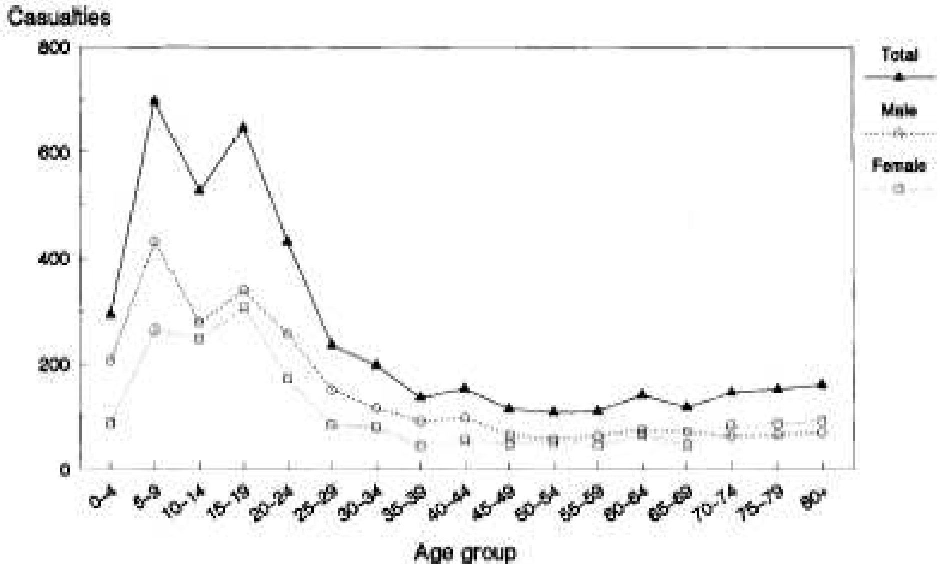
In pedestrian safety, risk is defined as "the probability of pedestrian collision/injury/fatality per unit of exposure" (e.g. Keall, 1995; Pucher and Dijkstra, 2000, 2003; etc.). In another word, the risk is derived from accident, but as a function of "exposure". According to different measures of exposure, the risk can be measured in macro level and micro level.

Macro risk

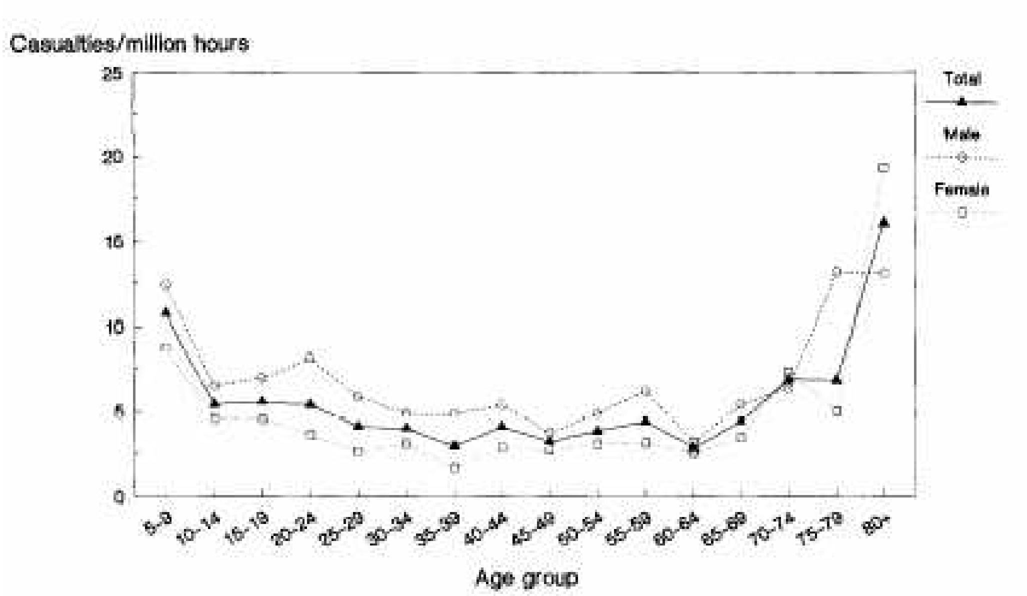
Measures of exposure used in the U.S. include "pedestrian distance travelled", "pedestrian trips made" (Pucher and Dijkstra, 2000, 2003) and "the number of streets crossed" (Roberts et al., 1996). In Europe, the most common measures include "the number of pedestrian trips made", "time spent walking" and "distance walked" (ETSC, 1999). By using the concept of "risk", firstly, at-risk groups can be identified, for whom their behaviour can then be investigated and attempts to modify it; secondly, locations where pedestrians are more at risk can be recognised and this can lead to the development of appropriate countermeasures (TRL, 1986).

For example, when the raw accident data are presented as a function of exposure, measured as the hours spent walking, a very different picture emerges (Figure 15). It shows that the age categories with the highest risk are those aged 80 and above and those ten and younger. Adolescents aged

15-20 do not have elevated risk levels; rather, the high numbers of fatalities in this category are due to the fact that adolescents spend more time walking than other age groups.



(a) raw accident data of casualties



(b) risk data of casualties per million hours spent walking

Figure 15: Example of comparison of raw accident data and risk data (source: Keall, 1995)

Micro risk

Micro risk is more focused on a given location, e.g. a certain intersection, measures of exposure include “pedestrian volume” (Davis et al., 1988); “the product of pedestrian and vehicle volumes at an intersection” (Older and Grayson, 1972), or the square root of that product (TRL, 2001).

For instance, $R = \frac{A}{PV}$ (Older and Grayson, 1972)

where,

R: pedestrian risk at a specific location
A: the number of pedestrian accidents in a given time period
P: pedestrian flow over the same, or another time period
V: vehicle flow over the same, or another time period

3.2.1.3 Drawbacks of accident analysis

Accident analysis is thought to be the most direct and objective way to estimate traffic safety, however, restricted by features of accident itself and complicated work of accident data registration and management, this method has several drawbacks (e.g. Korda, 1999; Lord, 1996; etc.).

- Accidents are always rare in a certain site, especially pedestrian accidents. Too small number could be misleading.
- Long time-span is required to collect enough accident data, especially for pedestrian accidents. Before-and-After analysis isn't suitable to solve urgent problems.
- Accident analysis is based on accident data with high quality and quantity, lack of a well developed registration and management system hampers accident analysis.
- Provision of detailed accident data is charged by certain authorities and not always available.
- Dark figure exists, which means unreported cases of accidents are the biggest limitation of accident analysis, especially for pedestrian accidents.
- Differences in exposure (the amount of walking) population profile, modal split, and other factors may explain many of the differences and need to be taken into account when making comparisons in different areas.

3.2.2 Characteristics of pedestrian accidents

Based on previous pedestrian accident studies, characteristics of pedestrian accidents are reviewed from the following aspects of distribution of accident time, weather conditions, locations, demographic characteristics of victims, alcohol and varieties of accidents.

Time

Time distribution in a day in different areas is inconsistent, but 16:00 ~18:00 can be recognised as the common period when pedestrian accidents frequently happened. Most accidents happened at workdays. Variation of time distribution in a day and in a week can be attributed to different background conditions in different areas (e.g. working time, holiday time, motorisation level, etc). Time distribution of months is similar. The highest number of nationwide pedestrian fatalities happened during winter months, mainly from September to January, with typical fewer daylight hours and more inclement weather (e.g. Häckelmann, 1976; Maier, 1884; Harruff, 1997; CRTAS, 2007; etc.).

Weather

In general, fewer daylight hours and more inclement weather leads to more accidents. Osborn (1997) found that a significant proportion of the accidents occurred when it was dark (38%) and/or wet (42%). Häckelmann (1976) found that darkness and wet will increase the severity of accidents, similar to the former conclusion of “rainfall increases the risks to pedestrians by a factor of three in daylight and about nine at night ” (Smeed, 1968).

Location

Pedestrian crashes occur most frequently in urban areas where pedestrian activity and traffic volume is greater, for instance, the commercial area (shopping area, restaurant, hotel etc.) is found to be related to increasing crash risk of pedestrians (Maier, 1984; Zegeer et al., 1985).

Studies in UK (Davies, 1999) claimed that types of hazardous intersections for pedestrian crossing include high-volume, high-speed and multi-lane intersections with complex signal phasing (or without any traffic control at all). Similarly, accident data of Darmstadt (2001~2005) revealed that pedestrian accidents concentrated at intersections along main roads in the CBD area with high speeds of motorised vehicles, large numbers of public transport vehicles and tram stations or bus stops nearby.

Furthermore, pedestrian accidents happened on the arterial roads are always severer than on neighbourhood streets (Maier, 1984) due to higher vehicle speed, a study by UK DOT (1987) showed that when vehicle speed rises from 20 mi/h to 40 mi/h, the chance of pedestrians’ death in an accident increased by eight times (from 10% to 80%).

Quaye (1993) evaluated the relative safety of pedestrians crossing at T- and X-intersections and pointed out that for the same vehicle and pedestrian flows on a hypothetical intersection, X-intersections were generally found to be safer than T-intersections for a vehicle flow above 100 vehicles per hour.

Researches done in Australia (Cairney, 1999) found that nearly half accidents happened between pedestrians and near side vehicles, while 25%~30% accidents related to far side vehicles, similar results came out in Darmstadt (Germany), about 45% accidents happened at the near side, while 30% at far side based on the accident data from 2001 to 2005.

Demographic characteristics of victims

Children (5-9) especially young boys and the elderly (60+) are most possible to be involved in the accidents , males are more likely to be involved in a crash than females (e.g. Häckelmann, 1976; Maier, 1884; Harruff, 1997; CRTAS, 2007; etc.).

Those over 60 years have more fatalities than younger people at signalised intersection, which can be mainly attributed to age-related physical factors, mobility, judgement, abilities to deal with emergencies and other experiences when crossing (cf. Section 2.1.2). Reasons for more aged pedestrians being involved in intersection accidents also due to their preference of crossing at intersections (cf. Section 2.1.3).

Alcohol

Similar to other traffic accidents, alcohol also contributes to pedestrian accidents. Hughes (1998) studied situations in UK and found that more than half of the pedestrian fatalities in the age groups of 21-24, 25-34, and 35-44 involved intoxicated pedestrians (55%, 57%, and 55% respectively). A study in the U.S. demonstrated that nearly one quarter of the fatalities were positive for alcohol (Harruff, 1998).

Vehicle types involved

Consequences are different when pedestrians are crashed with different types of vehicles, generally the heavier the vehicle, the more serious is the consequence, for example, accidents with trams are nearly 1.5 times severer than those with cars (Häckelmann, 1976).

Bus-related accidents are common, either because pedestrians violates the signal to catch a bus or the bus blocks the visibility between the pedestrian and the striking vehicle (Harkey, 2004).

There is a special kind of accidents involving Heavy Good Vehicles (HGVs) in UK. Of thirty-one accidents, four involved elderly pedestrians being hit while crossing the road directly in front of a HGV when the vehicle driver started to move from stop line, without seeing the pedestrians (Hughes, 1998). It is also proved by Robinson (1997), 16% of fatal pedestrian accidents involving HGVs were of this type.

Vehicle movements involved

Based on previous studies (e.g. Häckelmann, 1976; Harkey, 2004), more than 75% of pedestrian accidents occurred with through traffic and the consequence was normally severer than accidents with turning traffic, because speeds of through traffic were higher. Most of these accidents can be ascribed to pedestrian non-compliance including violating signals or crossing outside crossings.

Studies in the U.S. declared that approximately one out of five accidents at signalised intersections involved a turning vehicle hitting a pedestrian and the split between left-turning and right-turning accidents was about 60/40 (Robertson,1984). Similar situation exists in Darmstadt (2001~2005), crashes with turning traffic take the percentage of 15%, more than half of the turning-related accidents are involved with left-turning vehicles. Häckelmann (1976) found that the consequence of accidents with left turning vehicles are three to four times severer than with right turning vehicles. Most accidents involved turning traffic are mainly due to structural deficiencies , which results in high speed of turning vehicles and driver failing to yield to pedestrians.

3.2.3 Main reasons for pedestrian accidents

Improper behaviour of pedestrians and drivers is the direct reason for pedestrian accidents, besides subjective reasons of road users, the objective problems like poor visibility and signal control deficiencies contribute to the risky behaviour and accidents as well.

Improper pedestrian behaviour

(1) Pedestrian non-compliance is the dominant reason for pedestrian accidents.

About one-third of fatal crashes involving pedestrians resulted from pedestrians disobeying signals or making misjudgement while attempting to cross (NHTSA, 2000). Pedestrian false behaviour (e.g. signal violation) is claimed to be the 7th important reason for accidents with injuries in Germany, counting about 10% (Statistic year book, 2008). Statistical data in China shows that pedestrian signal violation contributes to about 17% pedestrian fatalities (CRTAS, 2005~2007). Meanwhile, previous studies on demographic characteristics of pedestrian behaviour (cf. 2.2.2.2) and accidents (cf. 3.1.2) revealed a consistent relationship of each other.

(2) Pedestrian improper "visual search behaviour" contributes to accidents with turning vehicles.

Pedestrians attempted very little visual search for turning vehicles when crossing at a signalised intersection, especially for vehicles coming from behind (Lord, 1997). "… pedestrians tended to search for potential threats during the DON'T WALK phase, but they did not search during the WALK phase" (Jennings, 1977).

Turning vehicles fail to yield to pedestrians

Pedestrian accidents happened with turning vehicles can be largely attributed to turning vehicles failing to yield to pedestrians. As mentioned by Andree (2007), the main risk for pedestrians at signalised intersections is the conflicts between pedestrians and turning vehicles, more serious is with left-turning vehicles or high speed right turning vehicles.

Visibility problems of vehicles and (or) pedestrians

- Visibility relates to photometric concerns, most important ones are "the visual size, the contrast with the background, the ambient light levels, the presence of glare, the colour etc." (Hills, 1980; Langham, 2003), which helps to explain that more accidents happened in winter time and late afternoon.
- Too small number of pedestrians, e.g. a single pedestrian is easy to be neglected (Lord, 1994).
- Parking vehicles or stationary vehicles on adjacent lanes (Craddock, 1992), particularly the space near to crossings are occupied by buses or trucks, will impede visibility of both pedestrians and drivers.
- Other physical visual impediments such as too high vegetation in the centre stripe affects on visibility negatively.
- The speed of vehicles should be taken into account, corresponds to the moving obstacles defined by Gibson and Crooks (1938), especially for left turning vehicles.

Signal control deficiencies

A study by Craddock (1992) mentioned if the following two features are present at the same time, concealed or misleading vehicle movements and unsaturated flow of vehicles, a major cluster of pedestrian accidents may be generated. Situations leading concealing or misleading movement include "asynchronous signalisation of lanes at the same stop line", "turning movements held by opposing flow", "vehicles queuing over a signalised crossing" and "different directional timing for traffic".

Thirteen types of "latent danger" developed by Häckelmann (1976) (Table 4), most of which are related to signal control, were claimed to contribute to pedestrian accidents at signalised intersections significantly. It was found that 80% accidents were led by latent dangers, and in which 21% with too long clearance time for pedestrians; 42% with too long red time for pedestrians, at least longer than 60s; 43% with tram station or bus stop nearby; 16% with improper intergreen time; 16% with short green time for pedestrians.

Table 4: "Latent danger (LD)" for pedestrians at signalised intersections

No.	Latent danger
LD 1	too long red-amber time for vehicles while big adopted clearance speed of pedestrians
LD 2	separated signal control for vehicles of different lanes
LD 3	too long clearance time for pedestrians
LD 4	too low utilization of green time for vehicles
LD 5	too long red time for pedestrians
LD 6	different length of green time for opposing traffic streams
LD 7	too short intergreen time
LD 8	too short green time for pedestrians
LD 9	latent dangers of refuge islands in the middle
LD 10	latent dangers at regulation "turning vehicles + pedestrians"
LD 11	complex situation because of complicated and big intersections
LD 12	tram station or bus stop near crosswalks
LD 13	zebra crosswalks

3.3 Traffic conflict technique (TCT)

3.3.1 Overview

"Traffic Conflict Technique (TCT)" was firstly proposed in 1966 by Hydén from Sweden and has been taken over and modified in other countries. New methods have been developed and used on estimating traffic safety especially at intersections.

The original definition of "traffic conflict" by Hydén was "an observable situation in which two or more road users approach each other in space and time to such an extent that a collision is imminent if their movements remain unchanged" and the task of TCT is to detect conflicts and scale the severity of conflicts (Hydén, 1977). TCT is thought to be able to overcome certain deficiencies in the accident based safety evaluation procedures by short time lasted and uncomplicated observation ,"three days of observations already give (normally) better estimates than waiting for three years of accident data" (Hydén, 1987).

3.3.2 Methods of pedestrian conflict observation

In this section, common methods used for pedestrian conflict observation are explained. Basically there are two types: subjective approaches and objective approaches.

Subjective approaches of TCT

Subjective approaches normally detect conflicts and scale the severity of conflicts by examining evasive actions and their impetuosity.

(1) The U.S. definition

This technique originates from a study conducted by Perkins and Harris (1968) that consisted of examining evasive actions or sudden braking. "Sudden changes in the speed movement" was used as evasive actions, for vehicles it includes braking, lane change and acceleration; for pedestrians it includes stopping, running and lateral movement to avoid conflicts.

Glauz and Migletz (1984) further developed the U.S. definition by stating that the action of the first user is atypical. It is not an action that every road user would perform under the same circumstances, although it need not necessarily be an infrequent or extreme action.

(2) Classification by severity of the evasive actions (CS)

It was mainly used in European countries, like Germany, France, etc. According to the German TCT handbook (Erke, 1985), pedestrian conflicts have been divided into two levels based on the impetuosity of evasive actions carried out to avoid conflicts.

- Level 1: Pedestrians stop walking or go back, increase or decrease walking speed to avoid the conflicts. There is enough time for them to take actions.
- Level 2: Pedestrians suddenly stop or take actions quickly to avoid the conflicts "at the last minute".

However, the hard criticism of the TCT led to the end of its systematical use and development in Germany after the publication of the Handbook by Erke (1985). The reasons mainly related to the bases of TCT and its uselessness and subjectivity (Pfundt, 1985).

Objective approaches of TCT

"Objective approaches" include a time-proximity dimension in the severity scale, the most commonly used objective figures are "Time-to-Collision (TTC)" and "Post Encroachment Time (PET)".

(1) Time to Collision (TTC): The time it takes for two traffic participants to collide if they continue on their present trajectory at the same speed.

TTC uses the speed and the distance between the two road users at the time of evasive action. A TTC is then computed by dividing the distance by the speed. However, according to Hydén (1987), conflicts under this definition could be considered dangerous by two means: a fixed TTC below 1.5 sec or a speed-dependent TTC.

(2) Post Encroachment Time (PET): The time difference over a common spatial point under the situations where no collision course prevails. It is a measure of how nearly a collision has been avoided. Small PET values indicate that two traffic participants have a short distance to one another, while zero PET values indicate a collision has happened.

Häckelmann (1976) defined safety lag (Δt_s) as "the time interval between the actual walking time of risk walkers (without right of way) after stepping into the street until clearing the collision area with the vehicle and the actual travel time of the vehicle (with right of way) from its position when pedestrian enters the street to its arrival at the collision area.". It is similar to the concept of PET. Linear correlation between safety lag (Δt_s) and risk factor (ri) has been established, and the minimum safety lag is 4 second.

Later studies have drawn similar results with that of Häckelmann (1976), for example, Malkhamah (1999) found out the mean Post Encroachment Time (PET) values less than 4 seconds at Pelican crossings. Zhao (2003) observed safety lags in China, and recommended the average value is 3.62s. Accordingly, we can set PET 4s as the boundary value of risky/safe condition when pedestrian cross on Red.

Drawbacks of TCT

First of all, the reliability and validity of TCT is the most critical issue when applying it instead of traffic accident analysis. Several studies have examined correlations between accidents and conflicts and, in many cases, results have been diverse and contradictory (Williams, 1981). It's no doubt that TCT failed to establish the universal relationship between conflicts and accidents in different situations (Tiwari et al., 1998).

Furthermore, the results appeared different when different methods are applied in the same place (e.g.) and the accuracy of each method varies from situations (e.g. Lord, 1996; Shbeeb, 2000; etc.).

In general, factors such as conflict definitions, location, road user behaviour, judgement of observers etc. influence the results of TCT significantly, which decreases the reliability and validity of TCT.

3.3.3 Pedestrian conflict types

According to the German TCT Handbook (Verkehrskonflikttechnik - Handbuch für die Durchführung und Auswertung von Erhebungen,1985), when observing traffic conflicts, not only conflicts, but also traffic encounters should be observed ("traffic encounter" developed into an important concept in TSA in Section 3.4.2).

Traffic encounters and conflicts can be recorded in a table shown in Table 5 and Table 6. Besides recording encounters/conflicts, other information like "vehicles drive on red", "pedestrians cross on red or during clearance time", and volumes of related traffic should also be observed.

Table 5: Table heading of recoding traffic encounters and volumes (source: Erke et al., 1985)

Location			Date		Sheet No.			C-child	Y-youth	
Intersection			Observer					A- adult	O-old	
Approach			Weather						G- group	
	1	2	3	4	5	6	7	8	9	10
							F	F	R	R
time	B	B	B	B	B	B	volume	volume	volume	volume
1										

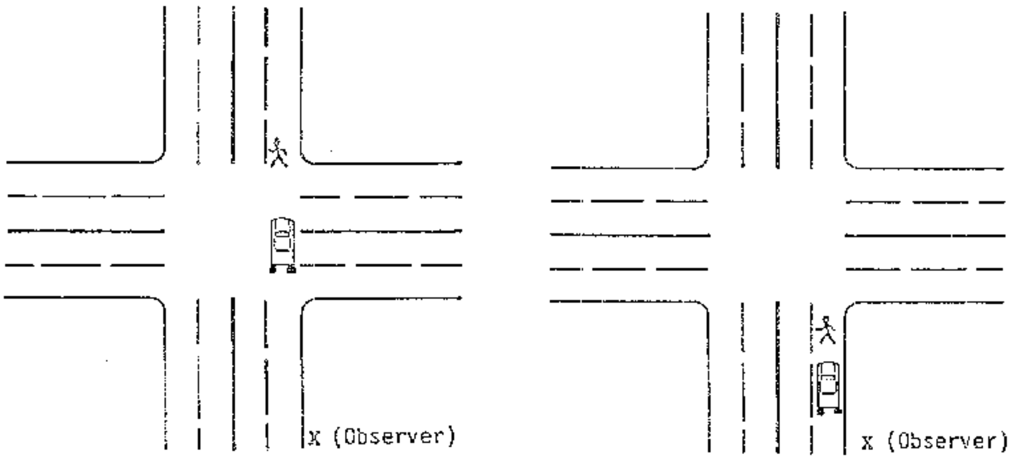
Conflicts between pedestrians and vehicles are categorised into three types:

- F LAB: conflicts between pedestrians and left turning vehicles (including U-turning)
- F GER: conflicts between pedestrians and through vehicles
- F RAB: conflicts between pedestrians and right turning vehicles

Table 6: Table heading of recoding conflicts between pedestrians and vehicles (source: Erke et al., 1985)

Location			Date			Sheet No.		F- Pedestrians Kfz- vehicles	
Intersection			Observer						
Approach			Weather						
	1	2	3	4	5	6	7	8	9	10
time	F LAB	F GER	F RAB	Kfz Red	F Red	F clear	stop	turn over	inside	outside
1										

In FHWA Handbook of conflicts observation (1989), pedestrian conflicts occur when a pedestrian crosses in front of a vehicle that has the right of way. The vehicle brakes or swerves, then continues through the intersection area. The conflicts are classified into two types according to the locations where conflicts occur: far side and near side of the intersection (Figure 16). No exact movements of vehicles and pedestrians are defined and it is lack of consideration of conflicts caused by vehicles.



Pedestrian far-side conflict Pedestrian near-side conflict

Figure 16: Pedestrian conflicts at far-side and near-side(source: Report FHMA-IP-88-027)

Tourinho et al. (2003) improved the FHWA classification (1989) by adding more information of movement of both participants, such as turning movements, as shown in Figure 17.

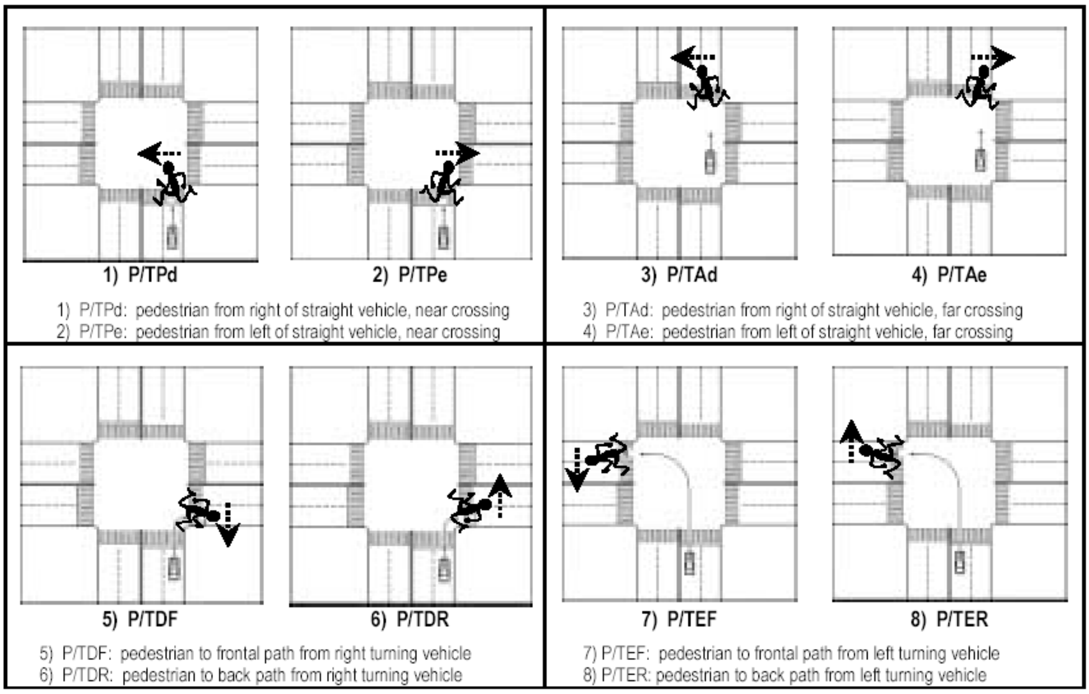


Figure 17: Types of pedestrian conflicts improved by Tourinho (source: Tourinho et al, 2003)

3.4 Traffic situation analysis (TSA)

3.4.1 Concept of situation

Traffic situation analysis (Verkehrssituationanalysen) is becoming one of the most important research methods on traffic safety, which developed from TCT and almost replaced TCT in Germany.

The concept of "situation" was first proposed by Angenendt et al. in 1987. A "situation" represents not only a momentary recording of traffic facilities and the environment, but also incorporated information on the behaviour of road users and attendant informal rules of behaviour. In another word, "situation" includes complexity of conditions and the related factors under which action takes place, which are traffic design, operation, field and behaviour related characters, and behaviour of involved traffic participants. Since a great amount of data is supposed to be collected, video investigation is quite helpful (Angenendt, 1987).

Take the situation data collected by Mennicken (1999) at zebra crossings for example, it included:

- volume of pedestrians and motorised vehicles
- speed of motorised vehicles
- characteristics of traffic participants
- layout characteristics of zebra crossing and other facilities around
- behaviour of traffic participants in the situation of interaction

Concerning crossings at signalised intersections, parameters related to intersection geometry and layout design, as well as signal control parameters are necessarily to be added.

3.4.2 Interactions and conflicts

Interaction occurs when traffic participants meet each other spatially and/or temporally, which means their intended trajectories cross or overlap each other. If traffic participants change their behaviour timely and can coordinate with each other, no conflicts happen at last, which is "encounter", defined by Erke (1985); if traffic participants approach each other spatially and temporally, they must take some critical manoeuvres to avoid probable "conflict", as shown in Figure 18. Valid critical manoeuvres by different traffic participants are listed in Table 7.

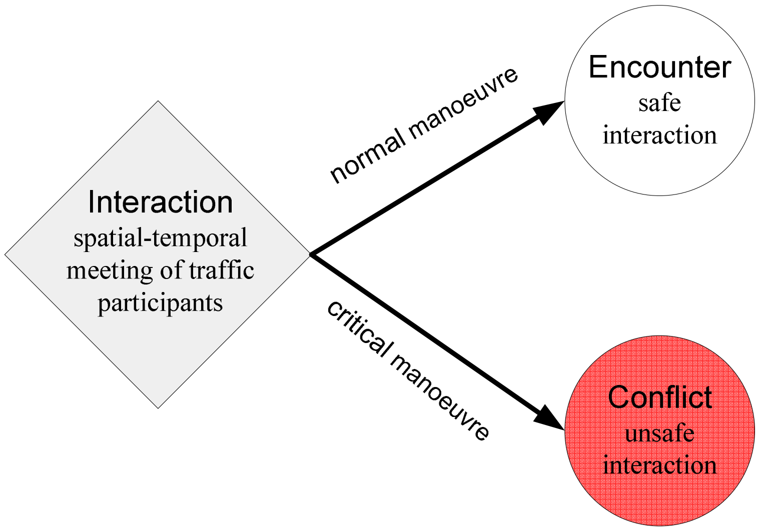


Figure 18: Relationship among interaction, encounter and conflict (source: Mennicken, 1999)

Table 7: Valid critical manoeuvres by different traffic participants (adapted by Mennicken, 1999)

vehicle drivers	cyclists	pedestrians
- brake - accelerate - change lanes/tracks	- brake - accelerate - change lanes/tracks - withdraw - change direction fiercely (e.g. turn over)	- change walking into running - suddenly stop/run back - change walking lines or jump back

Regarding pedestrian traffic, a previous research by Widbuch (1989) defined five serious levels of interactions at pedestrian zebra crossings. It was pointed out that interactions of level 0 (interactions following traffic regulations), level 1 (safe interaction, or "encounter") and level 2 (light interaction) can be observed quite often, while interactions of level 3 (serious conflict) and level 4 (near accident) are extremely seldom observed.

Referring on the definition from Widbuch (1989), the serious levels of interactions at crossings at signalised intersections are defined in Table 8.

Table 8: Levels of interactions at crossings at signalised intersections

level	definition	explanation	example
level 0	interaction obeying traffic rules	turning vehicles yield to GW	
level 1	safe interaction between vehicles and GW (namely encounter)	GW yield to turning vehicles	vehicles don't change speeds or tracks , GW stop and wait for vehicles passing or change routes
level 2	light conflict	manoeuvre executor	example
level 2a	interactions between vehicles obeying signals and LW/RW/EW (i.e. with pedestrian fault)	pedestrians	pedestrians: stop/ run / withdraw /change routes
level 2b		vehicles	vehicles take a controlled brake or a lane-change manoeuvre
level 2c		vehicles and pedestrians	above two together
level 3	serious conflict		
	fault of	manoeuvre executor	example
level 3a	vehicles	both	- vehicles: intense brake - pedestrians: suddenly stop /run / jump back
level 3b	pedestrians		
level 4	near accident	instinctive reactions	
level 5	accident		

3.4.3 Evaluation of traffic situation analysis (TSA)

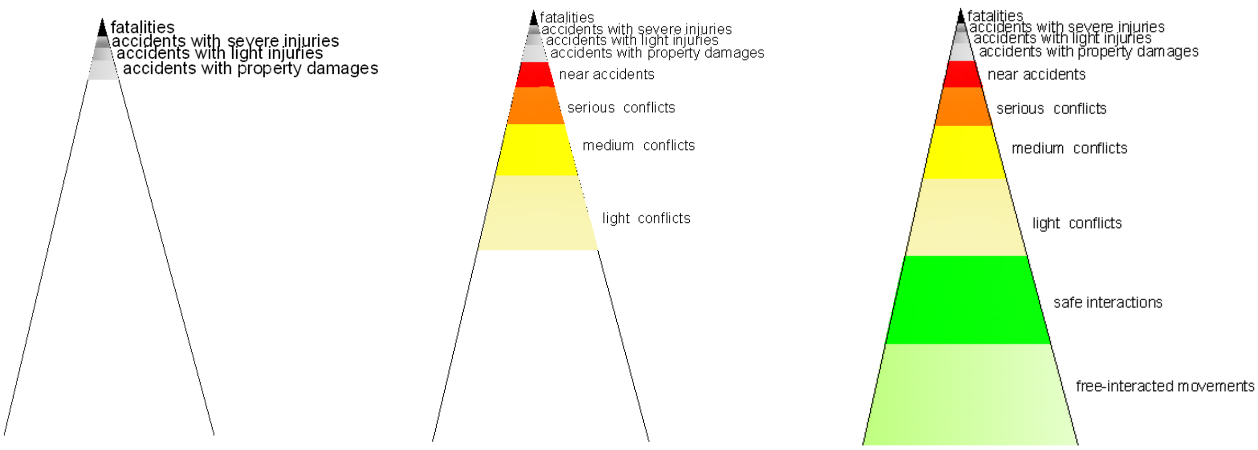
In general, traffic situation analysis (TSA) can very well describe the real situation. On the one hand, complete information of “traffic situations” including traffic conditions, intersection geometry and layout, signal control, road user behaviour etc. can be acquired; on the other hand, TSA distinguishes interactions (interactions obeying traffic rules and encounters)when pedestrians comply with signals from conflicts due to non-compliance by at least one of the traffic participants. Furthermore, from the definition of levels of interactions, who has fault behaviour and who is the manoeuvre executor can be clearly recognised. Moreover, manoeuvres of pedestrians are easily to be observed, so that the accuracy to evaluate interactions and conflicts can be high.

However, TSA failed to describe risky situations when manoeuvres are missing. For example, when a vehicle arrived at the conflict area shortly after a pedestrian left (e.g. the time interval is shorter than 4s), no manoeuvres are executed by either the vehicle or the pedestrian, but the situation is risky (PET<4 s, cf. Section 3.3.2).

3.5 Comparison of methods evaluating pedestrian safety

Three methods of traffic safety evaluation mentioned in Section 3.2-3.4 are compared from the aspects of data source, data availability, objectivity, completeness and data processing workload in Table 9.

- Data source: it reflects from where the data is acquired. The significant advantage of video recording is temporal situations can reappear and is repeatable.
- Data availability: it refers to the investigation procedure, representing how much effort is needed to get original data with required quality and quantity. The higher availability, the less effort is required.
- Objectivity: it reflects how much human judgement is required in the procedure of data processing. The higher objectivity, the less human judgement is required.
- Completeness: it reflects how much information can be concluded from observation and analysis, a comparison of methods mentioned above is shown in Figure 19.



(a) Accident analysis (b) Traffic Conflict Technique (TCT) (c) Traffic Situation Analysis (TSA)

Figure 19: Comparison of accident analysis, TCT and TSA (source: Mennicken, 2008)

- Data processing workload: it refers to the procedure of data analysis, representing how much effort is required for data processing.

Table 9: Comparison of methods evaluating traffic safety

method		data source	availability	objectivity	completeness	data processing workload
accident analysis		accident database	+(+)*	+++	+(+)*	+
Traffic Conflict Technique (TCT)	subjective	field observation /video recording	+++	++	++	++
	objective	video recording	+++	+++	++	+++
Traffic situation analysis (TSA)		video recording	+++	++	+++	++

Note: +++: high; ++:moderate ; +: low
*:depends on accident registration and management systems in different areas

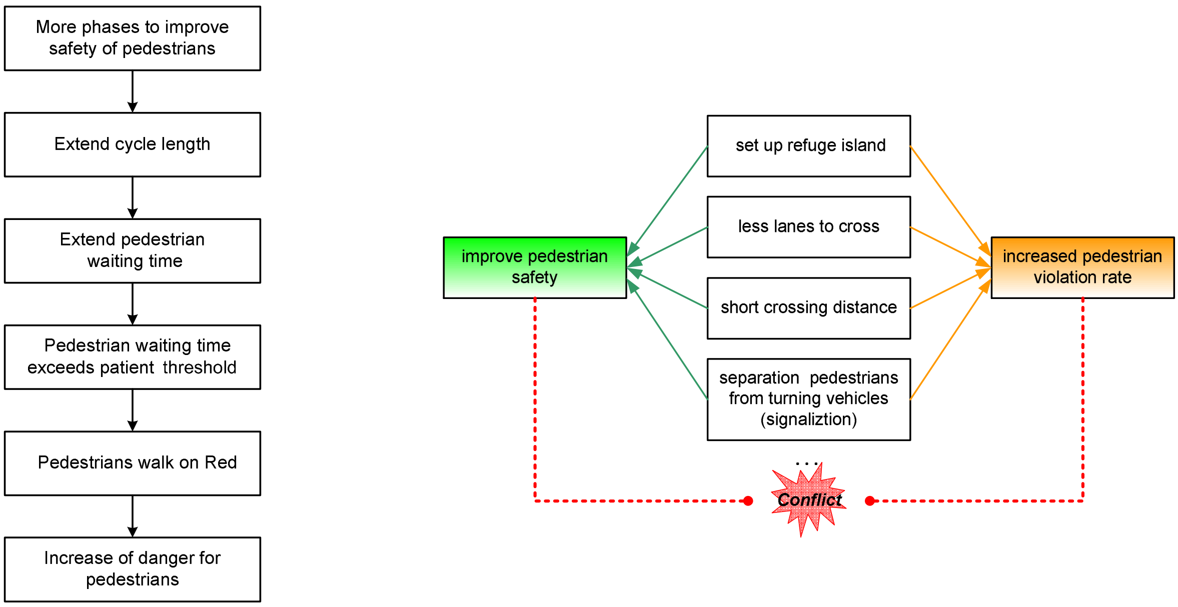
A general recommendation of applying above methods to evaluate pedestrian safety at signalised intersections is summarised as follows:

- Traffic accident data can indicate safety problems directly. Accident analysis is necessarily to be done when detailed accident data is available.
- Traffic situation analysis can clearly describe the real situation in details, pedestrian manoeuvres can be easily observed so that data availability is high and meanwhile, the data processing workload is moderate. Therefore, Traffic situation analysis (TSA) is recommended to be the most important method for empirical study on pedestrian traffic.
- Objective approaches of TCT are useful to judge risky situations when manoeuvres are missing. For example, when a vehicle arrived at the conflict area shortly after a pedestrian left, no manoeuvres are executed by either the vehicle or the pedestrian, the PET data is necessarily to be observed to judge the situation risky or not.

3.6 Influencing factors on pedestrian safety

Possible influencing factors on pedestrian safety are sorted into seven groups, as shown in Figure 21. The behaviour factors have the most direct impacts on pedestrian safety. Based on previous studies, age and gender, vehicle volume and speed, pedestrian volume, crossing distance, refuge island, bus stop/tram station nearby, parking vehicles, signal control relating to pedestrian waiting time and control strategy of turning vehicles, as well as traffic law enforcement and education have been supposed to be most important factors affecting pedestrian safety at signalised intersections.

However, it is hard to decide which factors are dominant. On the one hand, the factors play roles of different importance levels under different situations, e.g. a refuge island on a six-lane street seems more important than on a two-lane street; on the other hand, many factors influence each other. The correlation among these factors is complicated, some of them are consistent with each other, like the basic correlation among traffic volume, layout design and signalisation; while some of them have goal-conflicts, for example, signalisation of separating pedestrians from turning vehicles is supposed to improve pedestrian safety, but it results in more pedestrian signal violation due to longer waiting time (Hoffmann, 1990). Another example is goal-conflicts between decreased pedestrian crossing difficulty and increased pedestrian signal violation, as shown in Figure 20.



(source: Hoffmann,1990)

Figure 20: Goal-conflicts among influencing factors on pedestrian safety

3.7 Conclusions

Methods evaluating traffic safety including accident analysis, traffic conflict technique and traffic situation analysis have been explained and compared in this chapter. Concerning evaluation pedestrian safety at signalised intersections, traffic accident analysis is necessarily to be done when detailed accident data is available; Traffic situation analysis (TSA) is the most important method since it can clearly describe the real situation in details and it has advantages of high data availability, completeness and moderate data processing workload; And objective approaches of TCT are useful to judge risky situations when manoeuvres are missing.

Road user behaviour is the most important influencing factors on pedestrian safety and it has been proved that pedestrian non-compliance accounts largely for pedestrian accidents. Factors including background factors, human factors, intersection geometry and layout factors, traffic factors, signal control factors, traffic education and law enforcement factors have influences on pedestrian safety by influencing pedestrian and (or)driver behaviour directly or indirectly. Furthermore, these influencing factors play roles of different importance levels under different situations and the correlation among factors are complicated, some of them are consistent with each other, while some of them have goal-conflicts.

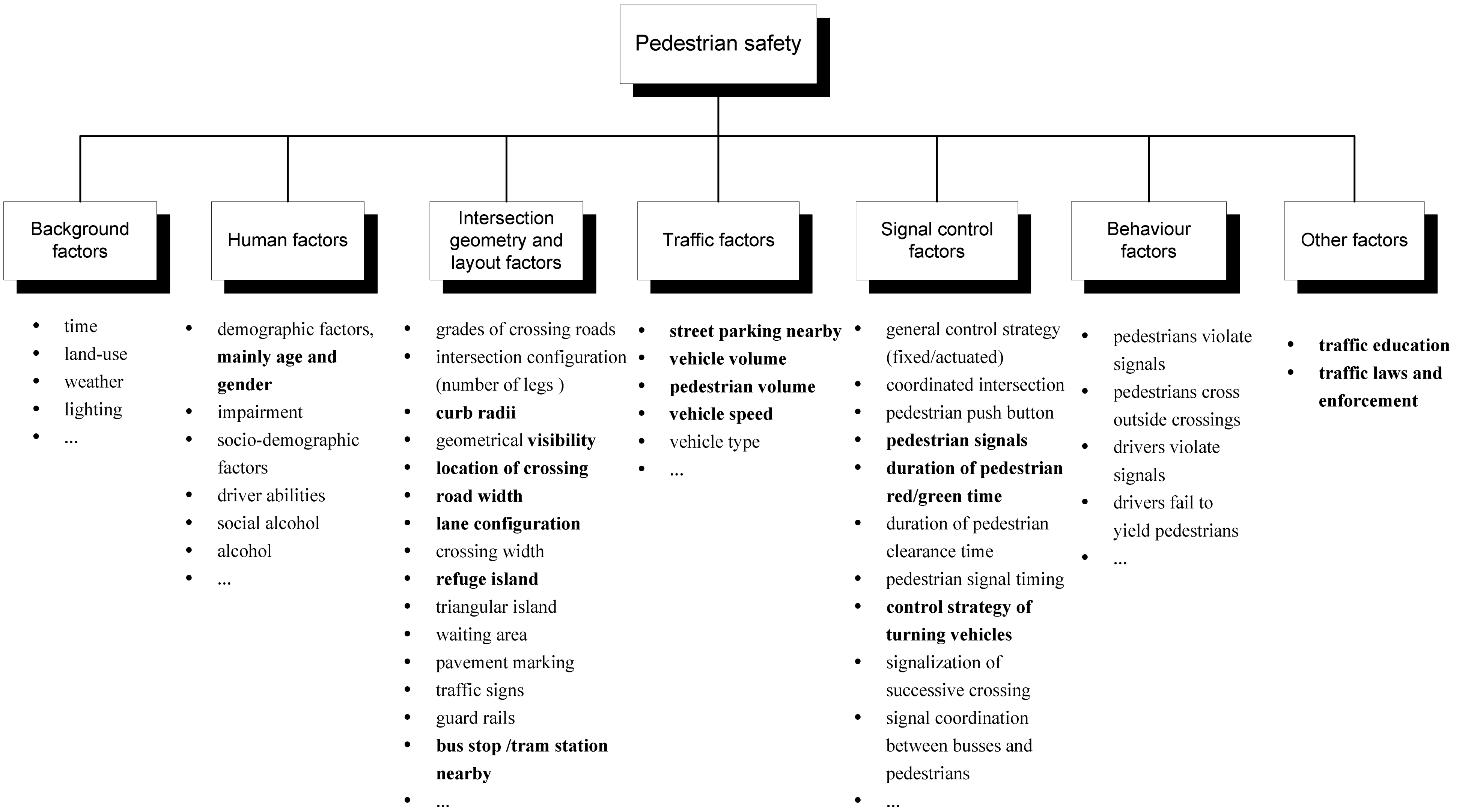


Figure 21: Influencing factors on pedestrian safety (Bold: most important influencing factors)

4. Comparison of pedestrian traffic in Germany and in China

4.1 Introduction

4.1.1 Chapter outline

As mentioned in Chapter 1, pedestrian safety level in Germany is much higher than that in China and it is helpful to improve pedestrian safety in China if useful experiences can be learned from Germany. However, before learning experiences, the basic step is to find out differences in aspects that mainly influence pedestrian safety in China and in Germany, and then highlight the problems in China.

Section 4.2 provides more evidence that Germany is worth taking as a good example on pedestrian safety through a comparison of statistical evaluation on pedestrian accidents in two countries.

Empirical research is the main part of comparison analysis. The motivation, aims and methodology of empirical research are explained in Section 4.1.2 and Section 4.1.3.

Relevant aspects for comparison include road user behaviour (cf. Section 4.3), practices of traffic engineering (cf. Section 4.4), traffic education (cf. Section 4.5) and traffic law enforcement (cf. Section 4.6).

Finally, the problems of pedestrian safety at signalised intersections in China are concluded in Section 4.7.

4.1.2 Motivation and aims of empirical research

As mentioned in Section 3.1.1, there is an advanced system of accident registration and management in Germany so that detailed accident analysis of pedestrian accidents at signalised intersections is available. On the contrary, pedestrian accident data with required quality and quantity in China is unavailable due to several reasons:

- accident registration and management system is not transparent in China, the dark figure exists seriously so that the reliability of published accident data in China is low, and
- detailed accident data such as recordings of accidents happened at intersections is charged by certain authorities and unavailable.

Therefore, pedestrian accident analysis at intersections in China is impossible, the most direct way to find out pedestrian safety problems in China can't be applied.

In order to find out the real situations of pedestrian safety and pedestrian crossing traffic at signalised intersections in China and compare it to the German situations, the only approach is to carry out empirical research to have observations at intersections in two countries.

Based on the motivation for empirical research, three aims of empirical research can be identified:

- obtain real situations of pedestrian safety at signalised intersections in Germany and in China,
- collect information of behaviour of pedestrians and drivers for comparison, and
- get information related to practices of traffic engineering, such as intersection geometry and layout design, signal control for comparison.

4.1.3 Methodology for empirical research

Empirical research is conducted in four steps, which are selection of investigated crossings, video recording, raw data processing, data analysis.

Step1: Selection of investigated crossings

Firstly, similar background conditions have to be ensured at investigated crossings to eliminate the influences of background factors like weather and time on pedestrian behaviour and make pedestrian demographic characters be similar by selecting crossings with similar land use nearby.

- Land use nearby: CBD areas
- Weather: dry
- Observation period: peak hours (noon peak) and off-peak hours in the afternoon

Secondly, in order to highlight the effects of intersection geometry and layout design, signal control, as well as traffic enforcement measures on pedestrian and driver behaviour, the following variable conditions are considered:

- road width and number of lanes to cross
- existence of refuge islands in the middle
- signal forms for pedestrian clearance time
- right-turn and left-turn phasing
- signalisation at successive crossings
- traffic wardens or policeman nearby

Furthermore, suitable shooting angles, available locations for establishing cameras should be considered for video shooting and views of crossings shouldn't be blocked by trees, poles etc. Totally there are ten crossings in China and nine crossings in Germany are observed, while video recording are only taken at seven crossings in China and eight in Germany due to video shooting restrictions, the detailed information is listed in Table 10.

Table 10: Overview of investigated crossings in China and in Germany

	No.	serial number(1)(2)	pedestrian clearance time(3)	right-turn phasing(4)	left-turn phasing(4)	signalisation at successive crossing(5)
in China	1	S(2,2,0)-1	FG	0	0	-
	2	S(2,2,0)-2	no	0	2	-
	3	S(2,2,0)-3	FG	0	0	-
	4	S(3,2,0)	FG(3s)+DARK(3s)	0	2	-
	5	S(4,2,0)	FG+CD	2	2	-
	6	S(4,3,0)	FG+CD	0	2	-
	7	S(4,3,1)	FG	-	0	2
in Germany	1	F(2,2,0)	R	2	2	-
	2	F(2,2,1)	R	-	2	1
	3	D(2,2,0)	Y	1	1	-
	4	D(2,2,1)	Y	2	2	2
	5	F(3,2,1)-1	R	1	1	1
	6	F(3,2,1)-2	R	2	2	2
	7	D(3,2,1)	Y	2	2	1
	8	F(3,3,1)	Y	1	1	1

Some notes to Table 10:

(1) S:Shanghai; F:Frankfurt am Main; D:Düsseldorf

(2) S(a,b,c): a: number of lanes at the entrance; b: number of lanes at the exit; c:if there is refuge island in the middle, c=1; otherwise c=0

(3) FG: Flashing Green; CD: Countdown facilities; R: Red; Y:Yellow

(4) 0:permissive; 1:permissive with lagging/leading time; 2:protected

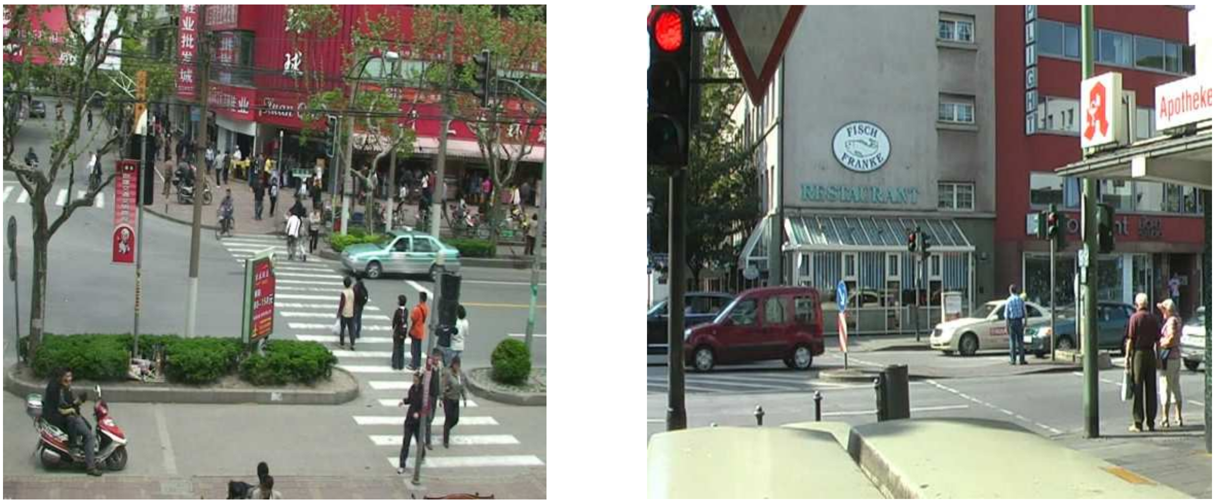
(5) 1:simultaneous; 2:separated

Step 2: Video recording

Videos of total duration of 280 minutes in China and 240 minutes in Germany are collected with the help of hard disk video cameras, since they can enable long recording time and provide with high image quality. The following elements are included in the videos:

- The whole pedestrian crossing with waiting areas at curb sides
- Pedestrian signal heads
- Process of pedestrian arrival and crossing
- Approaching of relevant turning vehicles

Figure 22 shows the examples of recorded crossings with video camera. It is better to set up video cameras in a higher position that helps to cover a broader area and make pedestrians more visible, without being sheltered from adjacent vehicles, particular buses and other heavy vehicles.



(a) Anshan Road in Shanghai (b) Berlinerstraße in Frankfurt

Figure 22: Examples of recorded crossings with video camera

Step 3: Raw data processing

Raw data to be collected from videos for further studies are listed in Table 11. Except behavioural data and PET data, the other data can be directly obtained from observation and counting.

Behavioural data are obtained indirectly by recording start times of each signal state and times of pedestrian arrival, starting and finishing by using subtitle software (e.g. subtitle workshop).

- start time of each signal state: the start time of Red, Green, Flashing Green, etc.
- pedestrian arrive time: the time when pedestrians arrive at curb sides or refuge islands

- pedestrian start time: the time when pedestrians start to enter the crossing from curb sides or refuge islands
- pedestrian finish time: the time when pedestrians finish crossing, either arrive at the other side of the street or refuge island in the middle
- numbers of pedestrians or vehicles involved in interactions/conflicts are recorded, levels of interactions/conflicts can be acquired when combining “who execute manoeuvres” and pedestrian crossing types.

PET data is required to be collected when it is less than 4s (risky situation). Risky situation has to be judged at first, then record arrival time of pedestrians and vehicles, the time interval is the PET value.

Table 11: Data to be collected from videos

No.	Data
1	background information: - location of intersection(grades of crossing roads, land use) - time and weather
2	sketch of intersection: - location of the crossing - lane configuration (number and types of lanes to cross) - road width - refuge island (with or without) - bus stop/tram station nearby (with or without)
3	signal and signalisation: - pedestrian signals, especially the signal form of clearance time - control strategies of turning vehicles - successive signalisation of refuge island - pedestrian signal program
4	volume of conflicting vehicles (per cycle) and pedestrians (p)
5	behavioural data (during observation period): - pedestrian crossing behaviour: GW, LW, RW, EW - pedestrian waiting time - pedestrian speed - Interactions/conflicts between pedestrians and vehicles
6	PET (Δt_s) when it is less than 4s

Step 4: Data analysis

Data analysis mainly includes following aspects:

- Calculate and compare performance indices in two countries based on the raw data. The performance indices in the research include:
  - absolute and relative proportion of GW/LW/RW/RW
  - proportions of pedestrians with interactions
  - risk factor
  - average interaction time of GW
  - average delay of GW
  - proportion of pedestrians involved in very risky situations

o pedestrian crossing speed

- Develop regression models of pedestrian behaviour based on statistical analysis of behavioural data.
- Compare important issues related to intersections layout design and signal control in two countries.

4.2 Statistical evaluation of pedestrian accidents

A general comparison of pedestrian fatalities in Germany and in China is shown in Figure 23 and Figure 24, the population and motorisation have been taken into consideration. Pedestrian fatalities per 100,000 population reached the highest point around 1980s in Germany, afterwards it started to reduce and then kept a steady low level since 1990s, similar trends appeared in China since 2002. The accidents all over China significantly decreased in 2003 because of sharply reduced trips due to SARS. However, pedestrian safety level in China is much worse than that in Germany, for example, in 2007 pedestrian fatalities per 100,000 motorised vehicles in China are about 18 times higher than that in Germany.

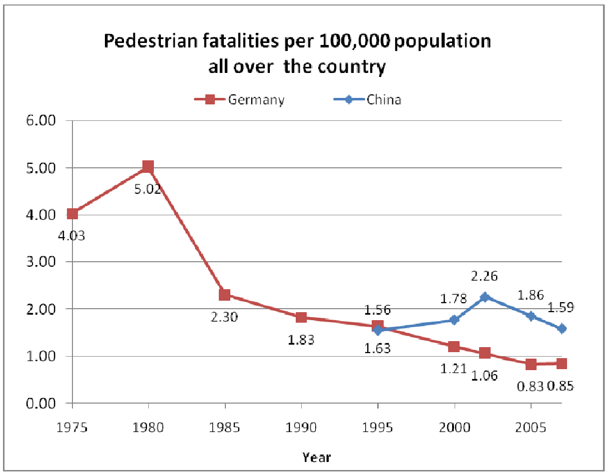


Figure 23: Pedestrian fatalities per 100,000 population in Germany and in China

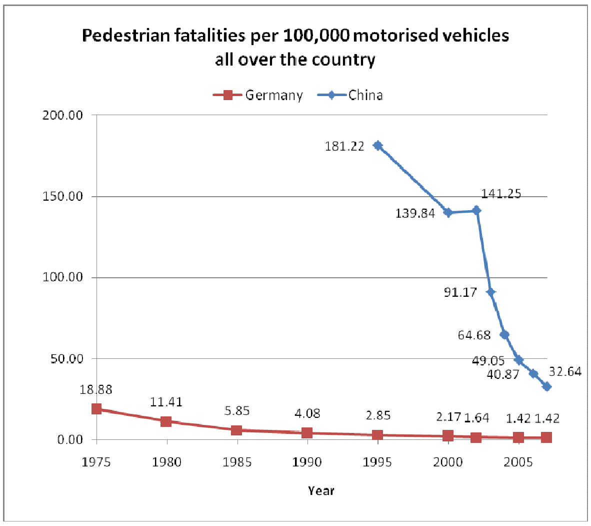


Figure 24: Pedestrian fatalities per 100,000 motorised vehicles in Germany and in China

Pedestrian fatalities and injuries take high proportions of all traffic fatalities and injuries in both countries, however, pedestrians are two times more often involved in fatalities and injuries in China than in Germany, as shown in Figure 25.

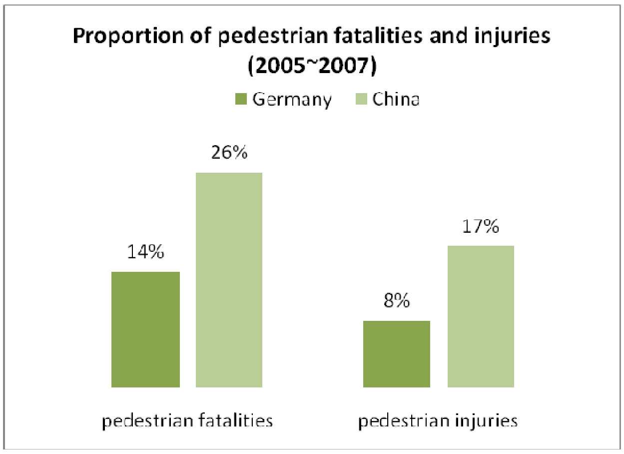


Figure 25: Proportions of pedestrian fatalities and injuries in Germany and in China

In Figure 26, a comparison of pedestrian fatalities and motorisation (private vehicle possession per 1000 population) in recent years (2002~2007) between the city of Shanghai (China) and Frankfurt am Main (Germany) is taken. It can be seen that motorisation in Frankfurt is 6.5 times higher than that in Shanghai, but Frankfurt has only 1/20 pedestrian facilities .

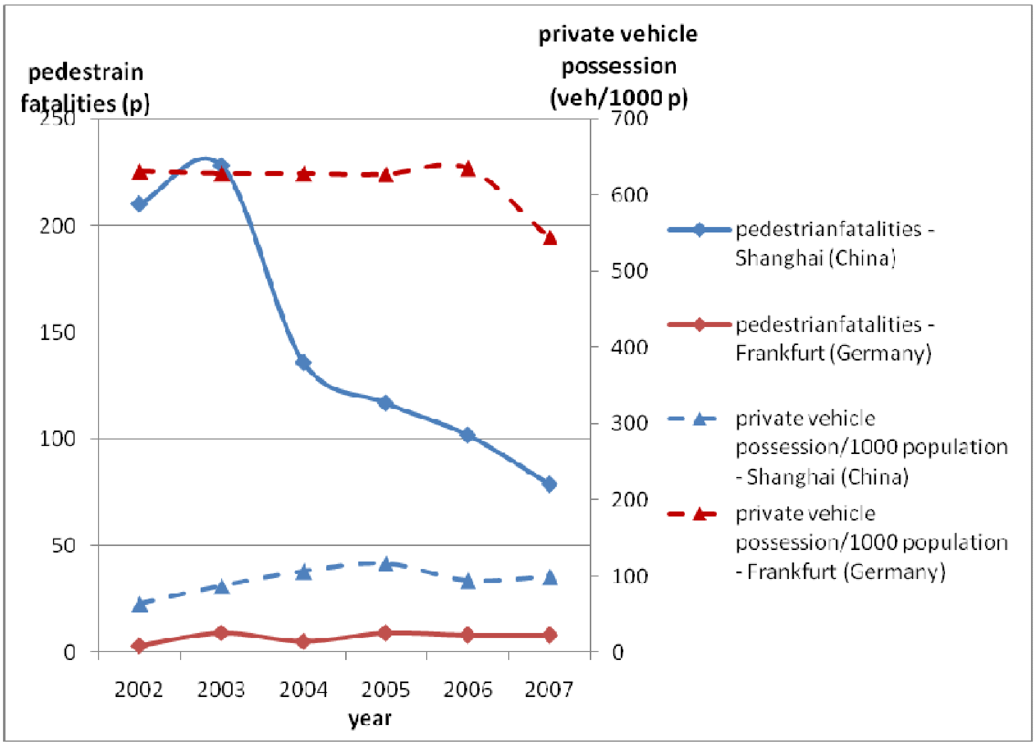


Figure 26: Pedestrian fatalities in urban area of Frankfurt am Main and Shanghai (source: Frankfurt am Main, 2002-2007; Shanghai, 2002-2007)

Pedestrian safety is even worse in some other big cities in China. For example, about 800 pedestrian accidents happened in average year from 2002 to 2005, and averagely 185 pedestrians were killed in Beijing.

Furthermore, with the development and increase number of electric bicycles in China recently, accidents between pedestrians and electric bicycles increase, and the consequence is much severer than pedestrian accidents with normal bicycles (Figure 27) due to the particular traffic characteristics of electric bicycles, they share bicycles lanes with normal bicycles but are heavier, faster and more similar to motorcycles.

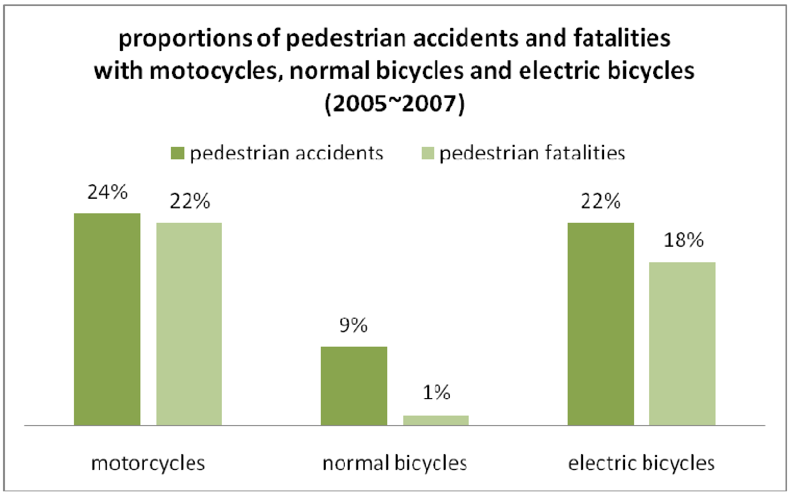


Figure 27: Pedestrians accidents with motorcycles, normal bicycles and electric bicycles

4.3 Empirical studies on pedestrian and driver behaviour

4.3.1 Pedestrian waiting time

Basically there are two concept regarding pedestrian waiting time, average pedestrian waiting time and observed pedestrian waiting time. The former is a theoretical value and used as the main criteria for evaluating pedestrian level of service (LOS) at signalised intersections while the latter is based on observation in reality. To a certain extent, the observed value can reflect the accepted waiting time by pedestrians before crossing on Red. A comparison of the two values can help to determine a reasonable value of waiting time for pedestrian level of service (LOS).

Average pedestrian waiting time

Average pedestrian waiting time (HBS, 2001; HCM, 2000) can be theoretically calculated according to Eq.1, assuming that pedestrian arrival follows uniform or random distribution and all pedestrians arriving on Red wait to cross until Green starts.

$$t_w = \frac{r^2}{2C} \tag{1}$$

where,

- t_w: average pedestrian waiting time (s/ped) if pedestrian arrivals are uniform or random(s)
- r: effective pedestrian red time(s), including displayed pedestrian red time and pedestrian clearance time
- C: cycle length (s)

Actually, based on the investigation at two crossings in China (S(4,3,1), S(2,2,0)-1), pedestrian free arrival (excluding pedestrian arrival from the adjacent crossings) follows Poisson distribution. However, the signal state has a certain impact on pedestrian approaching behaviour, most pedestrians speed up when they see Green or Flashing Green before they arrive at the crossing; When pedestrian signal is Red, around 25% of the pedestrians speed up if accepted gaps exist or there are pedestrians on the crossing, while the other 75% may slow down.

Observed pedestrian waiting time

Observed pedestrian waiting time at the curb side includes waiting time for Green (W_1) and pedestrian discharging time (W_2). Total waiting time of all pedestrians (W_1+W_2) can be calculated from the arrival-departure diagram (Figure 28). Same pedestrian arrival rate and signal program are assumed, the differences between theoretical departure line and departure lines in China and in Germany are the number of pedestrians crossing against signals and the discharging time of pedestrian platoons.

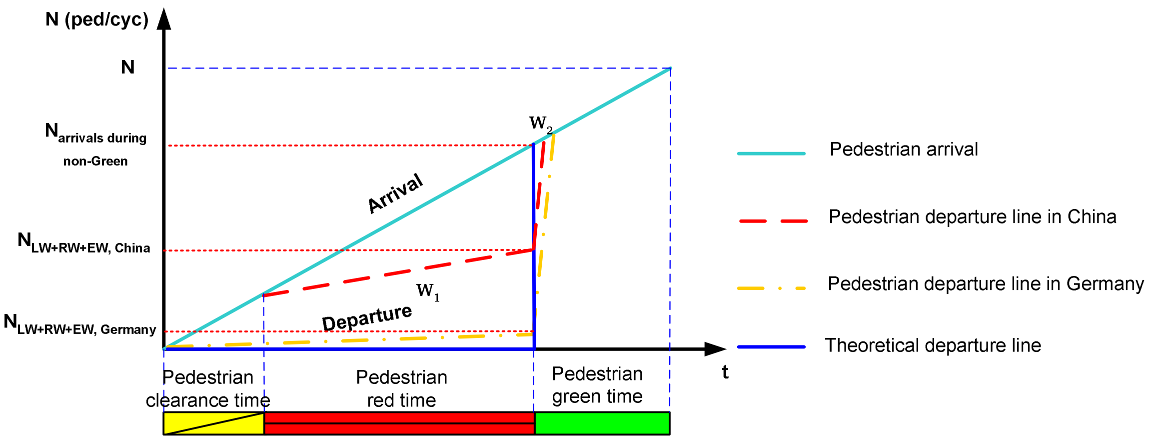
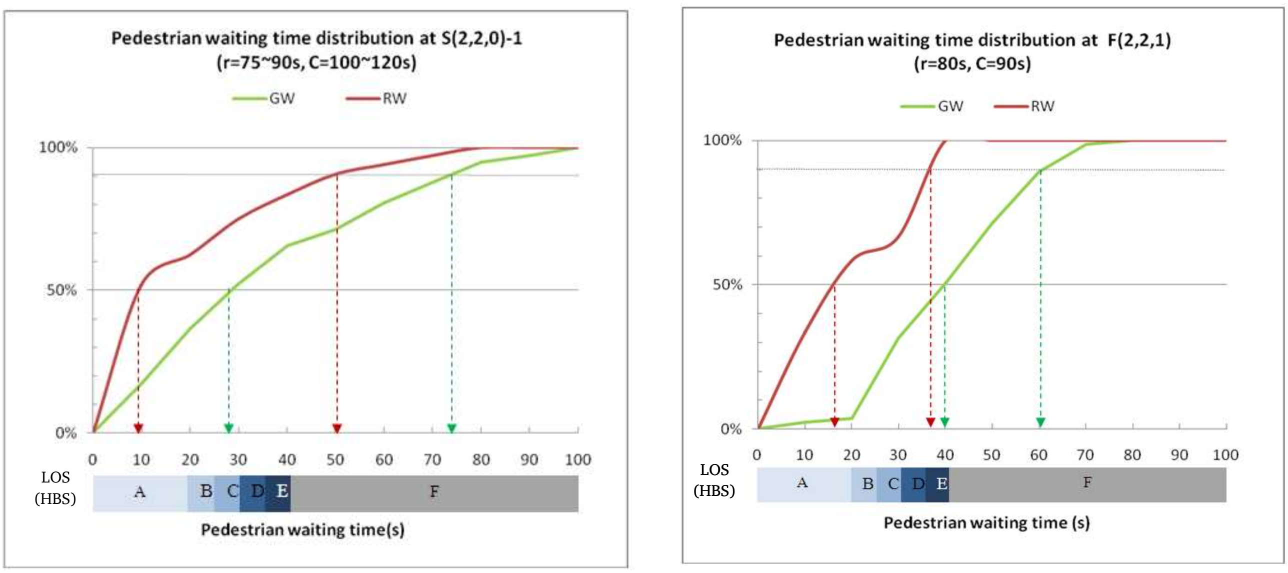


Figure 28: Diagram of pedestrian arrival and departure

Waiting time distribution of RW and GW is compared at two crossings in China and in Germany, where pedestrian red time and cycle length are similar, as shown in Figure 29. The 50th percentile waiting times of RW and GW are shorter in China because more pedestrians cross on Red rather than waiting for Green. The 85th percentile waiting time of RW can represent the threshold of pedestrian waiting time to a certain extent and is supposed to be consist with a LOS of E. The value at the German crossing is about 40s with E level of service according to HBS (2001); while it is 50s at the Chinese crossing with F level of service according to HBS (2001). Therefore, it can be concluded that the LOS criterial of average waiting time in HBS (2001) doesn't well suit Chinese situation, high values should be modified for China.



(a)China (b) Germany

Figure 29: Observed pedestrian waiting time distribution at example crossings

4.3.2 Proportions of RW, LW, EW, GW

Pedestrian crossing behaviour is classified into four types: GW, LW, RW and EW (cf. Section 2.2.2.1). Proportions of each type of crossing behaviour provide a general view of pedestrian non-compliance at intersections.

Absolute proportion is widely used in previous studies (cf. Eq.2), which considers all pedestrians arriving during observation period.

$$p_{abs-GW/LW/RW/EW}(\%) = \frac{N_{GW/LW/RW/EW}}{N} \times 100\% \quad (2)$$

where,

$p_{abs-GW/LW/RW/EW}$: absolute proportions of GW, LW, RW, EW (%)

$N_{abs-GW/LW/RW/EW}$: number of GW, LW, RW, EW during observation period (p)

N: total number of pedestrians during observation period (p)

However, a new measure of "relative proportion" is introduced in this study (cf. Eq.3), only pedestrians who arrive during non-Green time are taken into consideration. For example, relative proportion of GW represents a proportion of pedestrians who arrive during red and clearance time and wait to cross until Green starts.

$$p_{rel-GW/RW/EW}(\%) = \frac{N_{GW/RW/EW-(R+CT)}}{N_R + N_{CT}} \times 100\% \quad (3)$$

$$p_{rel-LW}(\%) = \frac{N_{LW}}{N_{CT}} \times 100\% \quad (4)$$

where,

$P_{rel-GW/RW/EW}$: relative proportions of GW, RW, EW (%)

P_{rel-LW}: relative proportions of LW (%)

$N_{GW/RW/EW-(R+CT)}$: number of RW, EW, GW who arrive during Red and clearance time during observation period (p)

N_{LW}: number of LW during observation period (p)

N_R: number of pedestrians arriving on Red (p)

N_{CT}: number of pedestrians arriving during clearance time (p)

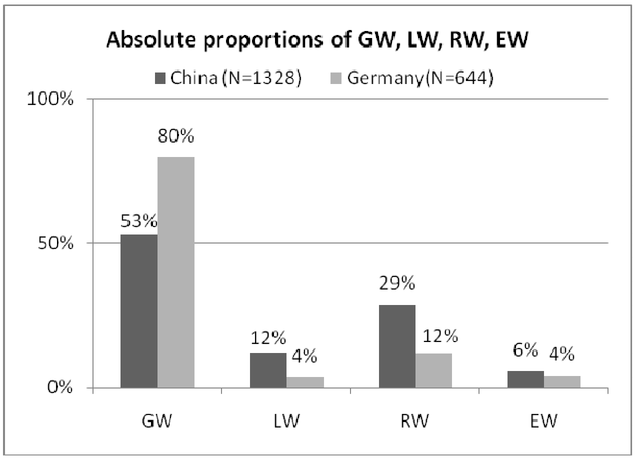


Figure 30: Absolute proportions of GW, LW, RW, EW

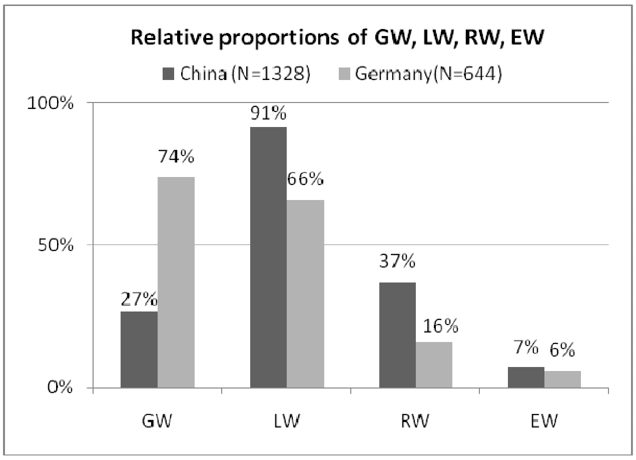


Figure 31: Relative proportions of GW, LW, RW, EW

Absolute and relative proportions of GW/LW/RW/EW from curb sides at investigated crossings in China and in Germany are shown in Figure 30 and Figure 31, following conclusions can be drawn out:

- According to the absolute proportions, pedestrian non-compliance appears more often in China than in Germany, since the absolute proportion of pedestrian crossing during non-Green in China (47%) is about 2.5 times higher than that in Germany (20%).
- Considering pedestrians who arrive during Red (namely Green for conflicting vehicles),

there are 44% of the pedestrians crossing against signals in China, while only 16% in Germany.

- Relative proportions of LW in both countries are high, it seems that most pedestrians attempt to seize the end of Flashing Green in China or beginning of Red (pedestrian clearance time) in Germany to avoid long waiting time. The relative proportion of LW in China is 1.5 times higher than that in Germany.

Model of pedestrian non-compliance

Statistical models of pedestrian non-compliance are established based on observation in China and in Germany. The models, on the one hand, are intended to explain the mechanism of pedestrian non-compliance in two countries, on the other hand, they are expected to predict pedestrian behaviour of non-compliance in Chapter 5. Linear regression is considered since this method has been extensively used in practical applications, particularly for the purpose of prediction.

According to the regression model, relative proportion of RW and EW(p_{RW+EW}) is claimed to have significant correlation with three variables (cf. Eq.5 and Eq. 6): average headway of conflicting traffic flow during pedestrian red time (h), average pedestrian waiting time (t_w) and pedestrian clearance distance (l).

$$p_{RW+EW,China} = 0.0454h - 0.0120l + 0.0119t_w \tag{5}$$

$$p_{RW+EW,Germany} = 0.0506h - 0.0030l + 0.0033t_w \tag{6}$$

$$h = \frac{r}{\sum_i \frac{q_i}{n_i} \times \frac{C}{3600}} \tag{7}$$

where,

p_{RW+EW}: relative proportion of RW and EW (%)

h: average headway of conflicting traffic flow during pedestrian red time (s)

l: pedestrian clearance distance (m), total length of the centre line of a crossing when there is no refuge island, or length of the centre line from the curb side to near edge of the refuge island in the crossing direction

t_w: average pedestrian waiting time (s/ped) (cf. Eq.1)

q_i: traffic volume of the *i*th stream (veh/h)

n_i: number of lanes related to stream q_i . n_i equals number of approaches of q_i when conflicts with pedestrians happen at the near side, n_i equals number of exit lanes when conflicts with pedestrians happen at the far side

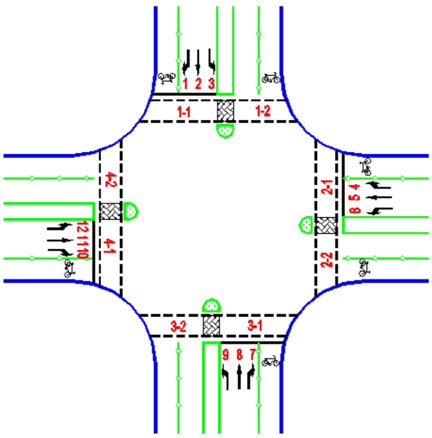
Table 12: Statistical tests of regression models

	China				Germany			
	t value	$t_{0.1}(3)$	F value	F(0.05)	t value	$t_{0.1}(4)$	F value	F(0.05)
h	8.254	1.638			5.633	1.533		
l	-5.184	1.638	441.59	0.0023	-4.370	1.533	26.74	0.0115
t_w	15.186	1.638			1.743	1.533		
			pass				pass	

Table 12 shows the results of statistical tests (t test and F test) of regression models. However, Chinese model has a higher goodness of fit than German one, it can be concluded that pedestrian non-compliance in China is a common phenomenon that can be attributed to several systematic inducement while in Germany it is a random event with lower frequency. Pedestrian waiting time plays more important role in China while the average headway is more dominant in German situations. It is consistent with the reality that pedestrians in China easily lose patience and would like to take risks to cross on Red even existing gaps are quite small, pedestrians crossing on Red in Germany are mostly seen when traffic flow interrupts for a long time.

4.3.3 Interactions and conflicts

Possible interactions and conflicts between pedestrians and different traffic streams at a standard four-arm intersection are listed in the interaction/conflict matrix (Figure 32). The traffic stream includes not only motorised vehicles, but also bicycles parallel released with motorised vehicles.



traffic stream / pedestrian	1	2	3	4	5	6	7	8	9	10	11	12
1-1	×	•	•									
1-2				×				•				×
2-1				×	•	•						
2-2			×				×				•	
3-1							×	•	•			
3-2		•				×				×		
4-1										×	•	•
4-2	×				•				×			

Note:
×: Interactions between GW and permissive turning traffic
•: Conflicts between RW/EW/LW and conflicting traffic

Figure 32: Interaction/conflict matrix

Additional interactions/conflicts happen between pedestrians and bicycles in China due to their battle for space. For example, bicycles stop ahead of the stop line, occupying part of crossings or pedestrians wait at bicycle lanes. Concerning different types of bicycles, interactions/conflicts with normal bicycles can be recognised to be safe, because manoeuvres can be easily executed by both pedestrians and normal bicycles in time. However, interactions/conflicts between pedestrians and electric bicycles ought to be taken into account, because the electric bicycles are always heavier, have higher speed than normal bicycles, and their trajectories are more flexible than vehicles, which brings new danger to pedestrians.

In order to describe interactions/conflicts quantitatively, the following performance indices are introduced in this research.

Proportions of pedestrians with interactions

$$p_{\mathrm{int/conf}-GW/LW/RW/EW} = \frac{N_{GW/LW/RW/EW-\mathrm{int/conf}}}{N_{GW/LW/RW/EW}} \times 100\% \tag{8}$$

where,

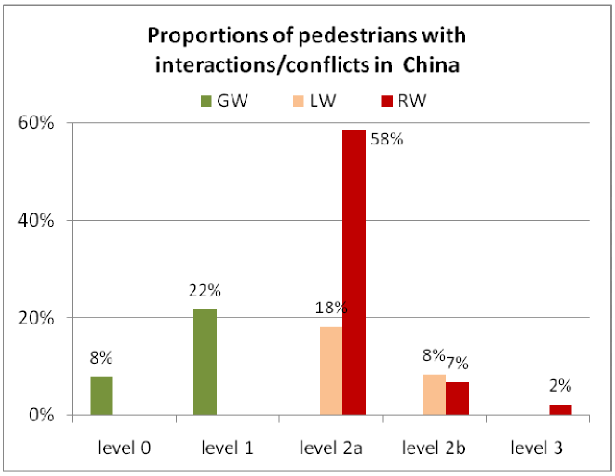
$p_{\mathrm{int/conf}\text{-}GW/LW/RW/EW}$: proportions of GW, LW, RW, EW with interactions (%)

$N_{GW/LW/RW/EW\text{-}\mathrm{int/conf}}$: number of GW, LW, RW, EW involved in interactions/conflicts (p)

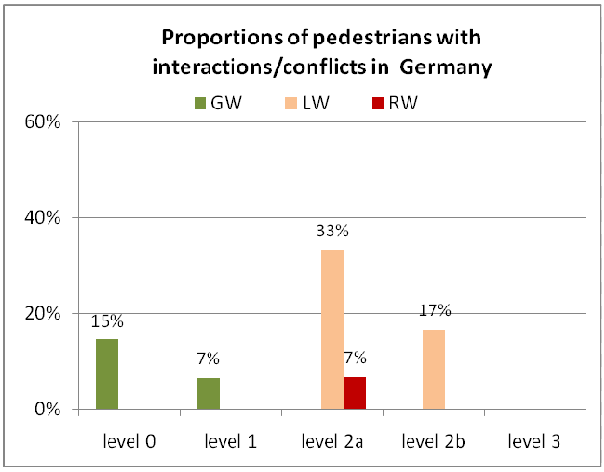
$N_{GW/LW/RW/EW}$: number of GW, LW, RW, EW (p)

Levels of interactions and conflicts have been defined in Section 3.4.2. Interactions of level 0 (interactions obeying rules) and level 1 (safe interactions) happen between pedestrians crossing on Green and permissive turning vehicles, while conflicts of level 2 (light conflicts) and level 3 (serious conflicts) happen between vehicles and pedestrians who cross against signals (cf. Table 8).

Interactions/conflicts can be seen at each crossing observed in China, while interactions/conflicts only happen at two crossings among the eight crossings observed in Germany. It is also found that level 0, level 1 and level 2 are common forms in reality in both countries, level 3 happen at times in China, while near accidents (level 4) and accidents (level 5) are not observed.



(a) China (N=1874)



(b) Germany (N=255)

Figure 33: Proportions of pedestrians involved in interactions/conflicts

Following results concerning proportions of pedestrians involved in interactions/conflicts are drawn out in Figure 33.

- GW are about 1.5 times more often involved in interactions in China (30%) than in Germany (22%). Vehicles yield to pedestrians more often in Germany, while in China is mostly the other way round.
- Totally 65% of the RW are involved in light conflicts (Level 2) in China, in which 58% of manoeuvres are taken by pedestrians who cross on Red (Level 2a); While in Germany, only 7% pedestrians crossing on Red are involved in light conflicts. It reflects that different attitudes towards non-compliance in two countries: most RW in China are prepared to be involved in conflicts during crossing, they prefer to cross lane by lane at multi-lane streets and accept smaller gaps, while in Germany most pedestrians crossing on Red only when they are sure that conflicting traffic is absent.
- More LW are involved in light conflicts in Germany.
- EW are seldom seen to be involved in conflicts in both countries.

Risk factor

Risk factor equals total number of interactions/conflicts divided by an "exposure", which is determined by pedestrian volume and relevant vehicle volume (cf. Eq.9). It represents the probability of a pedestrian involved in interactions/conflicts per unit of exposure.

$$R_{GW/LW/RW/EW} = \frac{n_{int/conf-GW/LW/RW/EW}}{(N_{GW/LW/RW/EW} \times Q_{veh})^{1/2}} \tag{9}$$

where,

$R_{GW/LW/RW/EW}$: risk factor of GW, LW, RW, EW (-)

$n_{int/conf-GW/LW/RW/EW}$: total number of interactions/conflicts with GW, LW, RW, EW involved (p*veh)

$N_{GW/LW/RW/EW}$: number of GW, LW, RW, EW (p)

Q_{veh}: volume of relevant conflicting vehicles (veh)

Number of interactions is calculated by multiplying number of pedestrians and vehicles involved in an interaction at one time, for example, if one pedestrian yields to two vehicles at one time, the number of interactions is 1*2=2; if one vehicle yields to five pedestrians, the number of interactions is 1*5=5.

For GW, Q_{veh} equals volume of permissive turning traffic; For RW and EW, Q_{veh} equals volume of conflicting traffic during pedestrian Red; For LW, since the exposure to vehicles differs from pedestrian enter time, the later a pedestrian enters, the larger the exposure will be, therefore, Q_{veh} equals half of the volume of vehicles of next conflicting stage.

Moreover, considering different traffic conditions at the near side (with entrance lanes) and far side (with exit lanes), risk factor at near-side and far-side are analysed respectively.

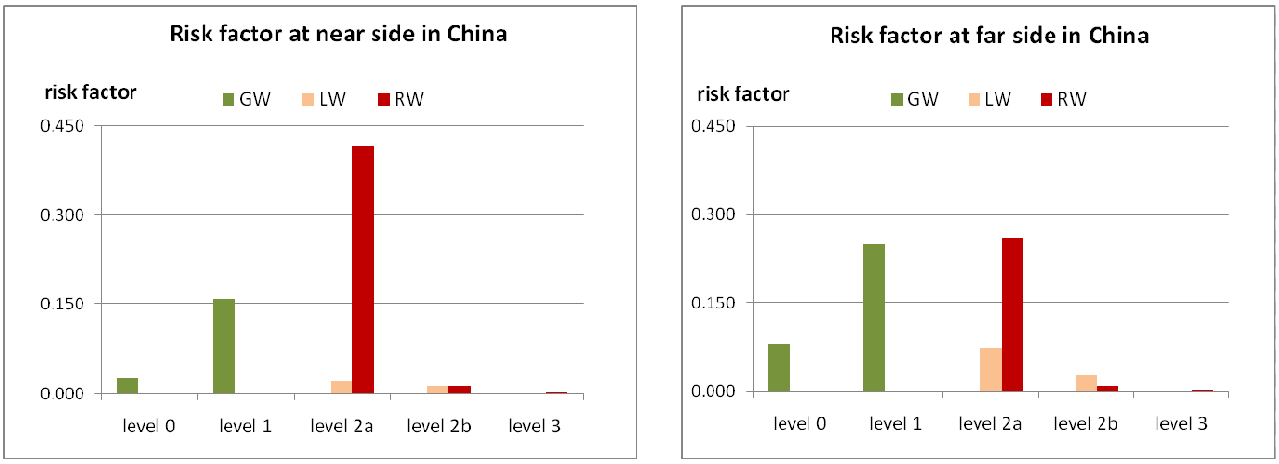


Figure 34: Risk factor at near side and far side in China (N=1874)

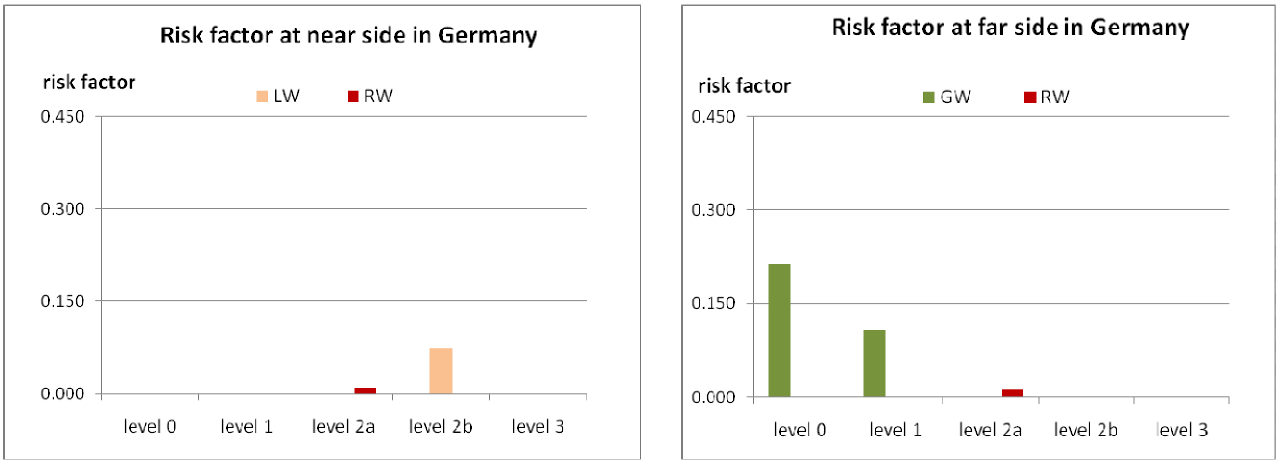


Figure 35: Risk factor at near side and far side in Germany (N=225)

Risk factor at investigated crossings in China and in Germany is analysed, as shown in Figure 34 and Figure 35. The value differences between China and Germany, between near side and fare side are listed as follows:

- Pedestrians crossing on Green have risks to interactions at near side in China while no risks at near side in Germany, since "Right turning on Red (RTOR)" is widely permitted in China but cautiously used in Germany.
- The majority of pedestrians crossing on Green yield to vehicles in China, while in most circumstances in Germany, vehicles yield to pedestrians.
- The probability of permissive turning vehicles yielding to pedestrians at far side is about two times higher than that at near side in China.
- Risk factor of RW in China is about 35 times higher than that in Germany.
- RW take high risks at near side in China while LW at far side, however, in Germany, RW have similar risks at near side and far side, and most conflicts involving LW happen at near side.

Model of total number of interactions/conflicts

In order to predict number of interactions/conflicts, a regression model is established based on the observation and it will be used in Chapter 5 for predict pedestrian behaviour of interactions/conflicts.

Previous studies have indicated close correlation between pedestrian accidents/conflicts and traffic volume (e.g. Zegeer, 1982; Zaidel, 1987). In this study, total numbers of interactions of GW (Level 0+Level 1) and conflicts of RW+EW (Level 2+Level 3) are regressed to have following correlation with volumes of pedestrians and relevant vehicle traffic during observation period (Eq.10). F test is passed and it proves a high goodness of fit.

$$N_{\text{int}/conf} = e^{0.996\ln(q_{ped})+0.652\ln(q_{veh})-4.071} \quad (\text{F}=24.65>\text{F}(0.05)=0.00017) \tag{10}$$

where,

$N_{\text{int/conf}}$: total number of interactions/conflicts during observation period

q_{ped}: number of pedestrians during observation period(p)

q_{veh}: number of conflicting vehicles related to types of pedestrians (veh), for GW, it equals volume of permissive turning vehicles; for RW and EW, it equals volume of vehicles which are released during pedestrian red time.

Average interaction time of GW in China

Pedestrians behave variously when yielding to vehicles, they may stop, slow down, speed up, withdraw or change routes etc, which brings additional time delay for pedestrians. The average interaction time of GW can be calculated according to Eq.11. The calculation results of average interaction time of GW is 1.6 s at observed crossings in China.

$$\overline{t_{level1}} = \frac{\sum_{i}^{N_{GW-evel1}} t_{i,level1} - (\overline{t_{GW-n}} \times N_{GW-level1})}{n_{level1}} \tag{11}$$

where,

$\overline{t_{level1}}$: average interaction time of GW due to yielding to permissive turning vehicles(s/interaction)

$\overline{t_{GW-n}}$: average crossing time of GW without interactions (s)

$N_{GW-level1}$: number of GW yielding to permissive turning vehicles (p)

$t_{i,level1}$: crossing time of the *ith* GW yielding to permissive turning vehicles (s)

n_{level1}: total number of interactions of level 1

Average delay of GW

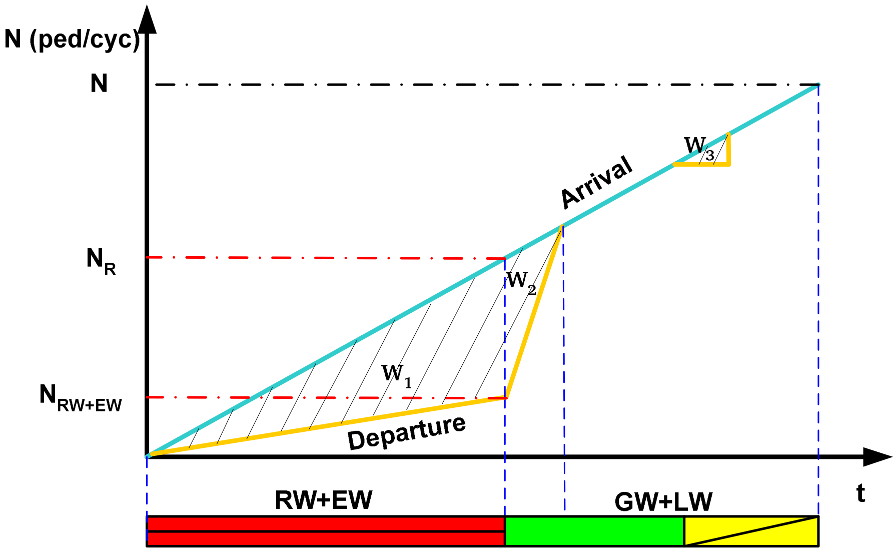


Figure 36: Diagram of pedestrian waiting time

Total delay of GW in a cycle includes three parts, which are waiting time for Green (W_1), pedestrian discharging time (W_2) equals the sum of the start-up loss time and release time of the platoon (cf. 5.3.1.1), and interaction time due to interactions with permissive turning vehicles(W_3). In Figure 36, the shadow area shows total delay of GW.

$$d_{GW} = \frac{W_1 + W_2 + W_3}{N_{GW}} \tag{12}$$

$$W_1 = \frac{(N_R - N_{RW+EW}) \times r}{2} \tag{13}$$

$$W_2 = 1.71 + 0.73 \times \frac{N_R - N_{RW+EW}}{w} \tag{14}$$

$$W_3 = n_{level1} \times \overline{t_{level1}} \tag{15}$$

where,

d_{GW}: total delay of GW (s)
W_1: waiting time for Green (s)
W_2: pedestrian discharging time (s)
W_3: total interaction time (s)
N_{GW}: average number of GW in a cycle (p/cyc)
N_{RW+EW}: average number of RW and EW in a cycle (p/cyc)
N_R: average number of pedestrians arriving during red time in a cycle (p/cyc)
w: width of crossing (m)

Proportion of pedestrians involved in very risky situations (PET< 4 s)

LW are more easily involved in very risky situations (PET< 4 s), especially at the far side since the oncoming vehicles are not expected to arrive so soon. For example, 77% of LW are involved at F(3,3,1) in the very risky situation. Besides LW, RW also have to face the risky situation in China, for example, 17% of RW have the average post encroachment time (PET) of 2.60 s at S(2,2,0)-1.

4.3.4 Pedestrian crossing speed

Pedestrian crossing speed equals crossing time, which includes both walking time and interaction time, divided by crossing distance. Average speeds of GW, LW, RW and all pedestrians are shown in Figure 37, EW is excluded because the sample size of EW is too small.

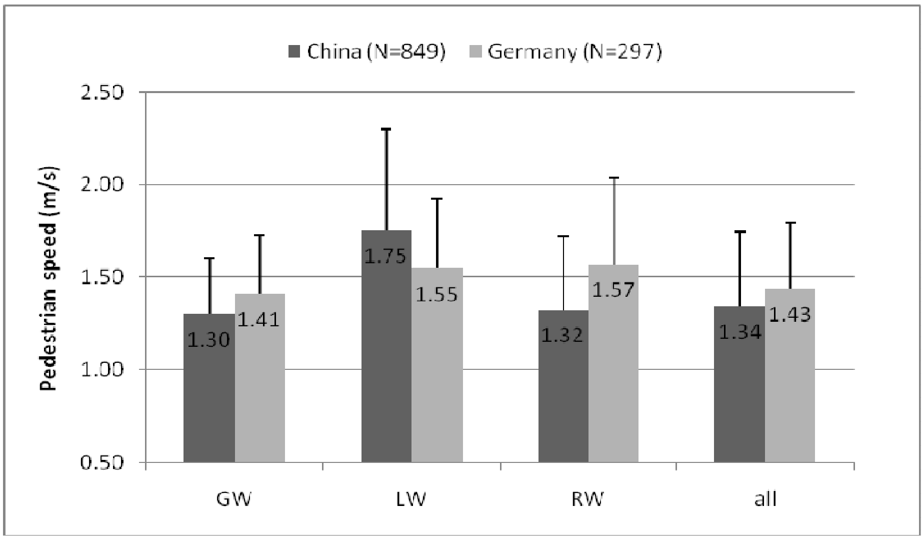


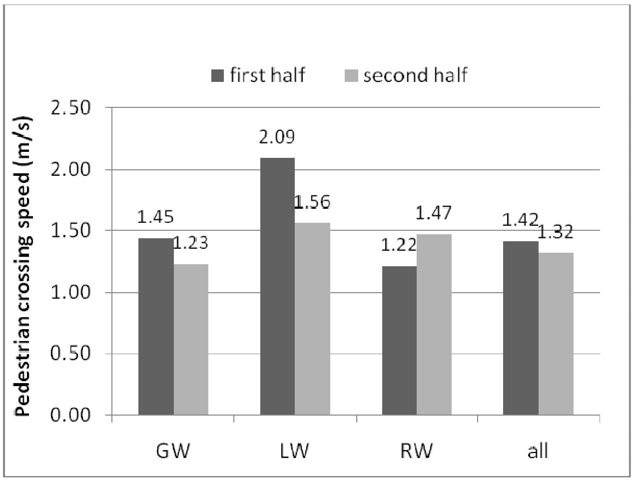
Figure 37: Mean and standard deviation of pedestrian crossing speeds

Pedestrian speeds are different during different signal periods in two countries.

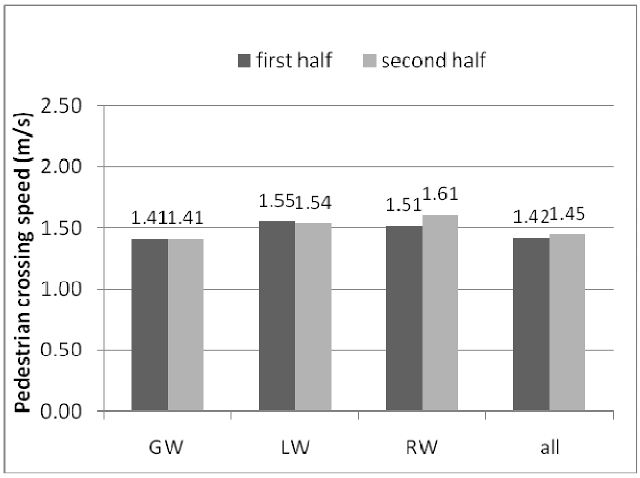
- The mean speeds of GW and RW in China are lower than those in Germany, possible reasons can be attributed as follows, on the one hand, both GW and RW have longer interaction times in China, on the other hand, pedestrians treat “crossing on Red” as normal behaviour and don’t realize its risks.
- Mean and standard deviation of LW crossing speed are significantly higher than other types of pedestrians in China.
- LW and RW have higher speeds in Germany and the speed of RW differs a lot under different traffic situations.

Refuge islands divide pedestrian crossing into two halves, namely first and second half according to the crossing sequence. Compare Figure 38(a) and Figure 38(b), it can be concluded that refuge islands have more significant impacts on pedestrian in China.

In China, GW and LW have lower speeds at the second half, it could be because pedestrians realize time is still enough to finish crossing and feel more relaxed. Speeds of RW at the second half are higher in both countries, since pedestrians who succeed in crossing the first half on Red intend to finish crossing and arrive at safe areas as soon as possible.



(a) In China (N=170)



(b) In Germany (N=297)

Figure 38: Pedestrian speeds at the first and the second halves of crossings

4.4 Traffic engineering regarding pedestrian crossing traffic

4.4.1 Relevant guidelines

The intersection layout design and signal control in Germany always follow periodically improved guidelines, such as RASt (2006) focusing on layout design, and RilSA (1992, 2003, 2010) focusing on signal control. Concerning pedestrian traffic in the urban area, a special guideline "EFA (2002)" contains more details. The HBS (2001), which is similar to the Highway Capacity Manual in the U.S., provides relevant methods of capacity calculation and evaluation on level of service. Figure 39 shows a simple correlation of these German guidelines.

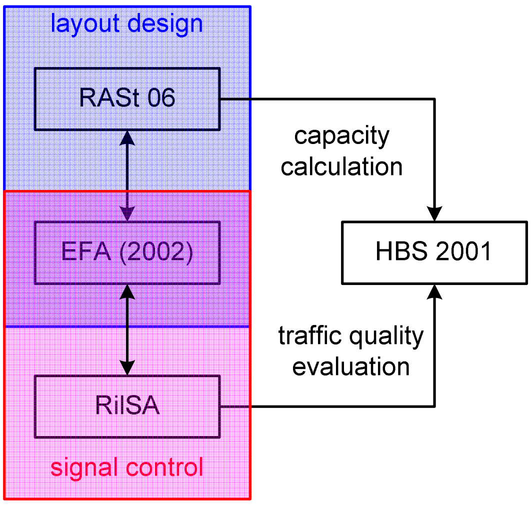


Figure 39: German guidelines related to pedestrian traffic at signalised intersections

Design issues with reference to layout design and signal control regarding pedestrian traffic at signalised intersections can be found in certain sections in the German guidelines, as shown in Table 13.

Table 13: German guideline sections of design issues with reference to pedestrians

<table>
<tr><th rowspan="2">aspect</th><th rowspan="2">design issues</th><th colspan="3">sections of relevant guidelines</th></tr>
<tr><th>RilSA (2003)</th><th>EFA (2002)</th><th>RASt (2006)</th></tr>
<tr><td rowspan="7">layout design</td><td>location of crossing</td><td rowspan="4">3.6</td><td rowspan="4">3.3.5</td><td rowspan="4">6.3.4.1</td></tr>
<tr><td>width of crossing</td></tr>
<tr><td>waiting area</td></tr>
<tr><td>separating strips</td></tr>
<tr><td>triangular islands</td><td>3.2.3</td><td>3.3.6.4</td><td rowspan="3">6.3.8.2</td></tr>
<tr><td>crossing of separate rails</td><td>3.5</td><td>3.3.5.2</td></tr>
<tr><td>coordination with bus stop</td><td>-</td><td>3.4</td></tr>
<tr><td rowspan="9">signal control</td><td>minimum green time</td><td>2.7.5</td><td rowspan="9">3.3.5</td><td rowspan="9">-</td></tr>
<tr><td>maximum red time</td><td>2.7.4</td></tr>
<tr><td>intergreen time</td><td>2.5</td></tr>
<tr><td>abortion of low-loaded vehicle green time</td><td rowspan="6">2.3.1.5</td></tr>
<tr><td>pedestrian requests</td></tr>
<tr><td>pedestrians and turning vehicles</td></tr>
<tr><td>signalisation at successive crossings</td></tr>
<tr><td>all green for pedestrians</td></tr>
<tr><td>crossing of separate rails</td></tr>
</table>

On the contrary, traffic engineering practices in China vary from areas because there are neither national standards on signal control nor on pedestrian traffic. Furthermore, some existing guidelines related to intersection design were developed in 1980s and haven’t been modified for a long period, which can’t suit the traffic situation nowadays.

4.4.2 Intersection geometry and layout design

Markings of crossings and regulations of the priority

Signalised crossings in Germany are normally marked with two parallel dashed lines, while zebra crossings are used only at unsignalised crossings where pedestrians have the priority, for example, the connection of the curb sides and triangular islands. In China, zebra crossings are used at both signalised and unsignalised crossings, pedestrian priority at unsignalised zebra crossings is regulated in traffic regulations, but always ignored in reality.

When bicycles are controlled by the joint signalisation with pedestrians, crossings for pedestrians and bicycles are normally separated in Germany, while at intersections without exclusive bicycle lanes in China, bicycles and pedestrians share the same crossing area, which results in a battle for space between them.

Location of crossings

RilSA (2003) claims that pedestrian crossings should be established as near the edge of parallel road as possible, if a crossing has to be placed back from the edge of the carriageway due to right turning vehicles, 5 to 6 m mustn’t be exceed. In China, crossings are either too close to the intersections or too far back shifted where there is no permissive right-turn traffic. When crossings are too close to the intersection, crossings of different arms connect or even overlap each other so that space for permissive right-turn vehicles yielding to pedestrians is unavailable. An example for comparison is shown in Figure 40.

(a) Darmstadt (2001) (b) Shanghai (2008)

Figure 40: Location of crossings

Curb radii

Reduced curb radii can reduce not only pedestrian crossing distance, but also speed of right turning vehicles. The former guideline regarding intersection layout design RAS-K-1 (1988) recommended the curb radius inside urban area to be 12~15 m, and in the new guideline RASt (2006), a minimum turning radius of 10 m is regulated. On the contrary, the curb radii in China are normally 15~25 m, some even reach 30m in order to have smooth right turning.

Lane configuration

Lane configuration includes numbers and types of lanes to cross and separating facilities between motorised and non-motorised traffic.

Crossings with more than five motorised lanes to cross (excluding exclusive bus lanes), which are composed of three or four approaches, two or three exits are quite common in China, while under most circumstances, there are no more than four motorised lanes to cross in Germany.

Majority intersections in China are with exclusive bicycle lanes, which are separated from motorised lanes by road markings, barriers or strips, the width of bicycle lane varies from 1.5 m to 5 m. While in Germany, bicycle lanes or approaches with the width of 1.6 m are only set at intersections in a certain bicycle network and they are separated from motorised lanes by road markings or coloured painting.

Additionally, special conditions of crossings with tram tracks or tram stations nearby are also common in Germany.

Refuge islands

Refuge islands can not only provide pedestrians with safe area in the middle of the road, but also shorten clearance distance and provide possibilities to apply more flexible pedestrian signal control. In Germany, pedestrian refuge islands are widely used for two-way-streets with four or more lanes. More than one refuge island are applied under particular situations, e.g. tram stations are nearby (Figure 41(a)) or more than four motorised lanes to cross in one direction (Figure 41(b)).

(a) Darmstadt (from Google earth) (b) Hamburg (from Google earth)

Figure 41: Examples of establishing refuge islands in Germany

On the contrary, refuge islands are seldom used in China even at large intersections. Too long crossing distances make pedestrians feel anxious and uncomfortable, especially for the elderly and disabled. A comparison of crossing design with same of motorised lanes to cross in Germany and in China is shown in Figure 42. Moreover, together with problems of insufficient pedestrian clearance time, pedestrians entering crossings at the end of Green are likely to be trapped in the middle of the road.

(a) Darmstadt (from Google earth, 2008) (b) Shanghai (2008)

Figure 42: Comparison of crossing design with same number of motorised lanes to cross

Channelisation of right turning

Establishing triangular islands is the basic way to channel right turning traffic at intersections. Triangular islands are normally established at oblique-angled intersections in Germany. Independently from the intersection angle, they are suitable for rapid right-turning movement together with a right-turning carriage. One of the advantages of triangular islands is to shorten pedestrian crossing distance of the main carriageway. The disadvantage is, firstly, due to large curb radii and disrupted crossing, detours can't be avoided and the intersections may become difficult to overlook; secondly, pedestrians are difficult to be protected by signalisation when crossing right-turning lanes (RilSA, 2003).

Triangular islands are not widely used in China, on one hand, pedestrians' priority at zebra crossings from the curb side to the triangular island is even more difficult to be guaranteed in China; on the other hand, existence of high volume of bicycles results in other problems, for example, safety problems at weaving section of bicycles and right-turn vehicles, insufficient area of triangular island to accommodate left-turn bicycles etc.

Pedestrian clearance distance

Pedestrian clearance equals the total length of the centre line of a crossing when there is no refuge island or length of the centre line from the curb side to near edge of the refuge island in the crossing direction if separate signalisation at successive crossing is applied.

Pedestrian clearance distance is determined by several layout elements including location of crossings, lane configuration, existence of refuge islands, triangular islands and dimension of curb radius, etc. Mainly due to improper location of crossings, exclusive bicycle lanes and larger curb radii, pedestrian clearance distance in China is about 10-15 m longer than that in Germany with same number of motorised lanes (Figure 43).

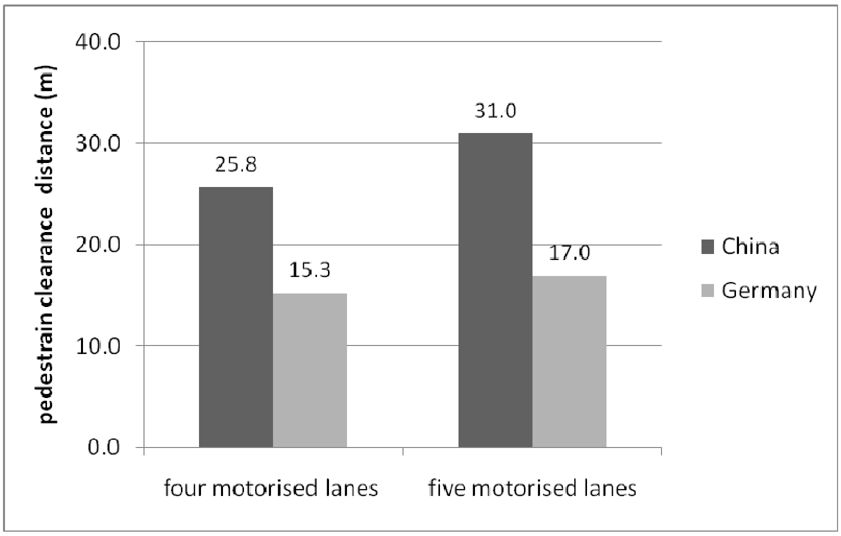


Figure 43: Comparison of pedestrian clearance distance with same number of motorised lanes

A comparison of clearance distances at ten crossings in China and nine in Germany shows that pedestrain clearance distance in Germany is normally less than 10 m, even the longest doesn't exceed 15 m, while in China, the average clearance distance is 27.5 m, the longest reaches 40 m. The larger the intersection is, the longer the clearance distance, since refuge islands are seldom established (Figure 44).

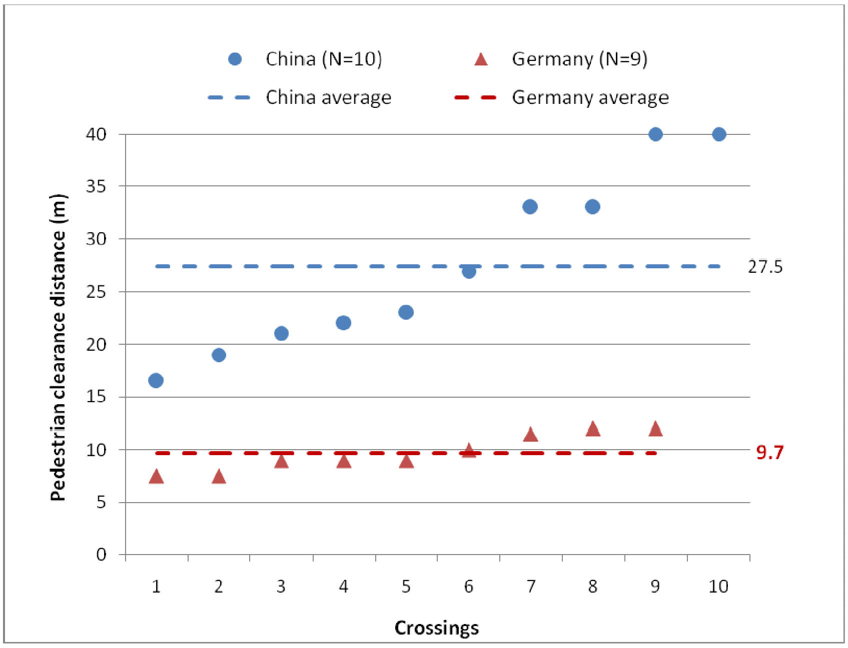


Figure 44: Comparison of pedestrian clearance distance at observed crossings

4.4.3 Signal control

General signal control strategy of intersections

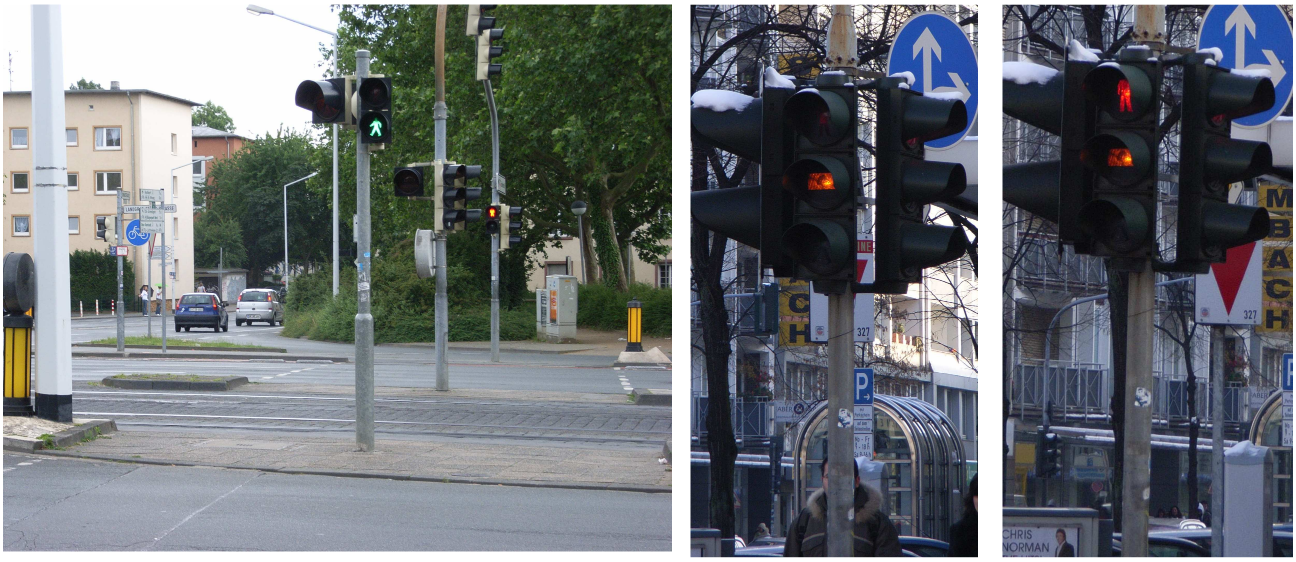
In Germany, traffic actuated control has been widely used at signalised intersections, which makes traffic signal control more flexible, also for pedestrians. For example, pedestrians can have an earlier beginning of green if the vehicle green time are not highly loaded (RilSA, 2003). Meanwhile, pedestrian push button is also widely used at intersections.

Fixed time control of single intersection is still the main control strategy in small and middle-scaled cities in China. Area control systems such as SCAT, SCOOT have been imported and some self-developed systems have been applied in big cities, like Shanghai, Beijing, etc., however, the effect is limited because of particular traffic characteristics in China, such as mixed traffic, low traffic discipline etc. Pedestrian requests at intersections are seldom considered.

Pedestrian signal indication

Pedestrian signal heads are established at far side both in China and in Germany. Pedestrian signal heads are also installed at the refuge island in the middle if the street is wide in Germany, while in China, lack of refuge islands on wide streets make it impossible to install pedestrian signal heads in the middle, too far distance of signal heads brings difficult for pedestrians with visual disabilities.

The standard pedestrian signal indications in Germany consist Green (walking) and Red (waiting), which is regulated in StVO, the traffic law in Germany (Figure 45(a)), and in Düsseldorf there is “yellow” and “red and yellow” signal indications for pedestrians as well (Figure 45(b)), in Hamburg countdown indication displaying remaining red time is applied at some mid-block crossings. When bicycles are jointly controlled with pedestrians, a joint signal with symbols of bicycle and pedestrian is applied. Furthermore, auxiliary signal of “flashing yellow with pedestrian symbol” is used to alert left-turning vehicles of crossing pedestrians.



(a) Standard two-colour pedestrian signal (Darmstadt, 2009)

(b) Three-coulour pedestrian signal (Düsseldorf, 2008)

Figure 45: Pedestrian signals in Germany

However, there is no regulated standard pedestrian signal indications in China, therefore, they are various from areas. There are several combination of signal indications and countdown facilities for pedestrians:

- Three- colour-signal head: Red (countdown)+ Flashing Green (countdown) + Green (countdown);
- Two- colour-signal head: Red countdown + Green countdown.

The green pedestrian symbol can also have movements, some even provides an increasing speed when it is near the end of green time. The countdown facilities have different forms, e.g. numbers or bars. Different from Germany, there is no bicycle symbol displayed when pedestrians and bicycles are jointly controlled.

Figure 46 shows some examples of countdown facilities with different signal indications in China and in Germany.

(a) countdown with Red in Nanjing, China

(b) countdown with Flashing Green in Shanghai, China

(c) countdown with Red in Hamburg, Germany

Figure 46: Examples of pedestrian countdown facilities

Cycle length and duration of pedestrian red time

Cycle length observed at intersections in Germany is around 70~90 s, which follows the requirement of RilSA (2003); However, cycle length varies in China from 70 s to 240 s, the average cycle length of nine investigated intersections in Shanghai is 156 s, as shown in Figure 47.

Pedestrian red time (include pedestrian clearance time at most crossings) is less than 60 s at most of the investigated crossings in Germany, which ensures pedestrian maximum waiting time less than 60 s, satisfying the requirement regulated in RilSA (2003). While in China, pedestrian red time (excluding pedestrian clearance time) exceeds 90 s at more than half of the investigated crossings, the longest one even reaches 180 s.

Average pedestrian waiting time determined by cycle length and pedestrian red time in Germany is distributed from 10 to 35 s, with a pedestrian LOS from A to D according to HBS (2001). In China, average waiting times at investigated crossings are from 30 to 90 s, and most of them exceed 60 s. Pedestrian LOS is quite low and most of them belong to level F according to HBS (2001). Signal control in China mostly only considers vehicle traffic and the threshold of pedestrian waiting time is neglected.

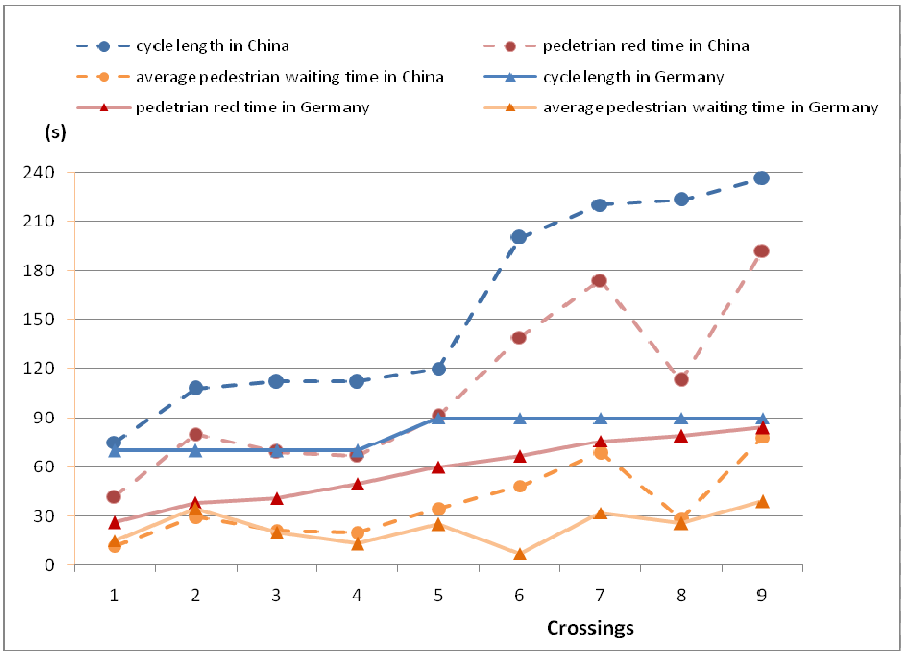


Figure 47: Cycle length and duration of pedestrian red time at observed intersections

Duration of pedestrian green time

According to RilSA (2003), the minimum green time should ensure pedestrians to cover half of the crossing distance, which can also be fulfilled at the majority of observed crossings in China, as shown in Figure 48.

Since pedestrian green time is mainly determined by parallel vehicle green time in China, problems arise when a major street intersected by a minor street is crossed, pedestrians crossing the main street may not have sufficient green time if traffic at the minor street is low.

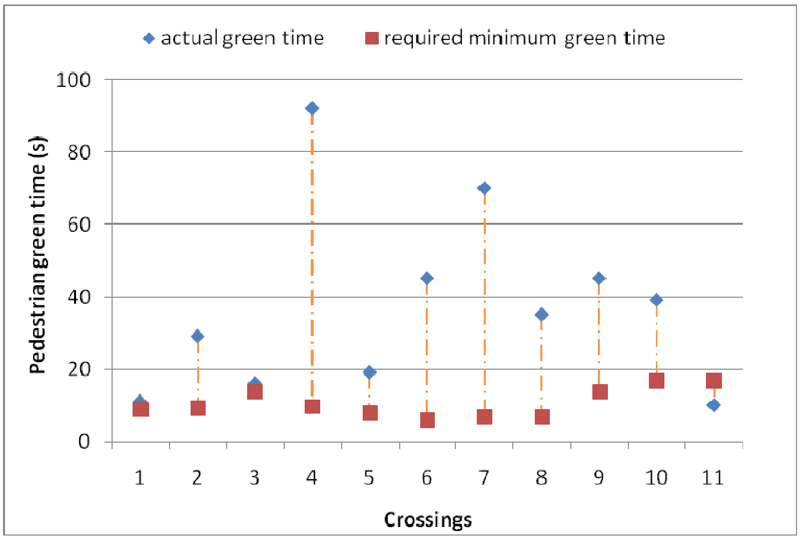


Figure 48: Observed pedestrian green time in China and required values by RilSA (2003)

Pedestrian clearance time

Safety is the most critical issue during phase transition, pedestrian clearance time aims to make pedestrians entering crossings at the end of Green be able to cover the total clearance distance.

Except yellow signal in Düsseldorf, steady red is the main form of pedestrian clearance time in Germany. The duration of pedestrian clearance time is strictly calculated according to pedestrian clearance distance and clearance speeds (1.2 m/s~1.5 m/s).

While in China, there are many deficiencies concerning pedestrian clearance time.

- unclear definition of Flashing Green

Flashing Green or combined with countdown facilities is the main form indicating pedestrian clearance time in China, but meanings of Flashing Green haven't been clearly defined in traffic laws or relevant guidelines. Most pedestrians recognise Flashing Green only as an alert signal for speeding up, nearly no pedestrian waits when Flashing Green is displaying.

- insufficient pedestrian clearance time

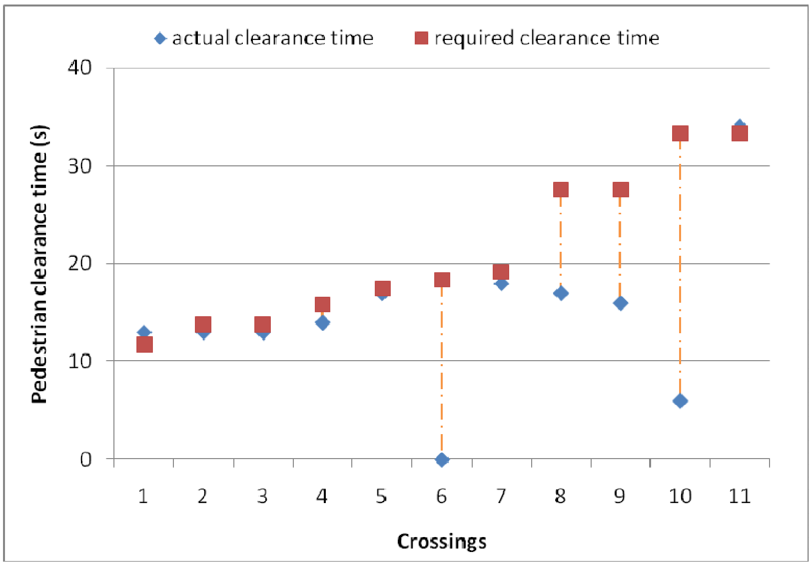


Figure 49: Observed pedestrian clearance times in China and required values by RilSA (2003)

Nearly all of the pedestrian clearance time investigated in China is shorter than required time by RilSA (2003), as shown in Figure 49. At some crossings, there is only 3-6 s of Flashing Green time before pedestrian red starts, which can not really play a role as "clearance time".

- lack of pedestrian clearance time

Two-colour-signal indication in China contains no signal indicating pedestrian clearance time, since the countdown timer displays remaining green time until zero, then after 3 second all-red time, conflicting vehicles start. Decisions of walking or waiting have to be made by pedestrians themselves completely depending on their experiences and personalities (aggressive or conservative), which may increase more indeterminacy threat of pedestrian safety.

Signalisation of turning movements

It has been widely accepted in Germany that additional phases for turning traffic extend pedestrian waiting time, which easily induces pedestrian signal violation, therefore, protected phasing is only used in particular conditions such as the existence of large proportion of children, the elderly and handicapped pedestrians, or large proportion of heavy vehicles.

Permissive phasing with auxiliary protection of pedestrians is recognised as an efficient way and is widely applied in practice.

- "Time lead at conflict area" is recommended in RilSA (2003) and also widely applied in practice, "the green time beginning have to be offset, allowing pedestrians or cyclists to step onto the crossings 1 or 2 seconds before a turning vehicle arrives".

- The lagging right turning green time is used, for example, at an intersection crossed by arterial road and minor road (e.g. F(3,2,1) at Berlinerstraße), right-turn traffic from the minor road is released when pedestrian clearance time starts.
- Flashing yellow signals with a pedestrian symbol are installed to alert drivers of crossing pedestrians.

In regard with right turning movements, free right turning is recommended to be prohibited at the crossings with triangular islands, zebra crossings or signalised crossings must be applied and the former is better since it won't increase additional waiting time for pedestrians (RilSA, 2003). Meanwhile, right turning on Red (Green Arrow) is seldom adopted in Germany nowadays concerning safety considerations.

However, in China, control strategies of left turning vehicles are simply determined by the grades of streets, permissive left turn phasing is generally used at minor streets, while protected left turn phasing at main streets. Lack of consideration of traffic volume leads to a reduction of capacity, what is worse, large gaps appearing during pedestrian red time induces pedestrian non-compliance.

Regarding right turning movements, permissive right turn phasing is used in most of the intersections, but pedestrian leading interval or warning signals are missing. "Right turning on red" is widely permitted in China.

Signalisation at successive crossings

According to RilSA (2003), basically there are three signalisation at successive crossings, which are simultaneous, progressive and separate signalisation.

- Simultaneous signalisation is widely used in Germany in order to avoid pedestrians to wait in the refuge island.
- Separated signalisation is used when the crossing distance is too long (exceeds 10 m) and the refuge island is big enough to accommodate waiting pedestrians.
- Progressive signalisation is seldom used due to possible misunderstanding of signals by pedestrians and right turning drivers. Different colours of signals at two sides may induce pedestrians cross on Red as oncoming pedestrians are still given Green, and right turning drivers may assume red for pedestrians and try to impose their wrongly assumed priority.

Separate signalisation is commonly applied in China, especially at big intersections. The signalisation is well accepted by pedestrians since it is helpful to provide pedestrians with longer green time in a cycle. Refuge islands without signal heads on them can be recognised as simultaneous signalisation, which is often seen in China.

Exclusive pedestrian phase

The biggest advantage of exclusive pedestrian phase is to eliminate conflicts between pedestrians and vehicles completely. The disadvantages include "the minimal green time for pedestrians will decrease, double release for pedestrians is not possible, long waiting time and the release of parallel vehicles during pedestrian Red will increase signal violation (Andree, 2007)".

Exclusive pedestrian phase is not so common in Germany, while in China, exclusive pedestrian phase and diagonal crossings are established at some intersections with large pedestrian volume, for example, in a shopping area, with traffic wardens guiding pedestrians to behave correctly.

4.5 Traffic education

It is claimed that the aim of traffic education is to rectify deficiencies in the safety of individual knowledge and attitudes of road users, and special attentions should be paid to the risk groups, for example, the children (Funk and Wiedemann 2002).

Traffic education is attached high importance in Germany and an education system covering all ages is well developed. Traffic education starts from kindergarten, courses are given at school; traffic lessons (lessons carried in the schools), as shown in Figure 50, and trainings (e.g. the drive school, mobile clubs etc.) are the main approaches for adults.

As an initial education, the children in the kindergarten are put in a "real situation" and are asked to play different roles of road users (pedestrians, cyclists and drivers); the traffic regulations are orientated to the older children, for example, to teach the children to put on lights on the clothes or put on reflective clothes when it is dark. In many cases, there is a training cooperated with a traffic police and partly taken at some special practice places (e.g. driver schools) where traffic regulation can be taught in a real traffic situation without hazard.


In der Jugendverkehrsschule der Kreisverkehrswacht lernen Kinder wie sie sich im Straßenverkehr zu Recht finden

„Das Linksabbiegen ist besonders schwer"

„Besonders schwer ist das Linksabbiegen", erklärt die zehnjährige Tabea. Grund: man muss erstens beim Handzeichengeben kurz einhändig fahren, weiter auf den Verkehr und möglichen Gegenverkehr achten, dabei auch noch den Blick über die Schulter nichtvergessen. Gseller sieht alles und macht sofort auf Fehler aufmerksam. Auch mit Lob ist er nicht sparsam, wenn das Erlernte richtig umgestzt wird.

Gseller macht den Job in Zusammenarbeit mit der Kreisverkehrswacht bereits seit mehr als 27 Jahren, sein Kollege Schöfl seit 23 Jahren. Auch wenn es natürlich eine gewisse Routine gibt, erleben sie die Kinder doch stets neu. Und zu wissen, dass ...

Handzeichen geben zum Abbiegen, nur eine Übung in der Verkehrsschule.

Figure 50: Example of children traffic education in Germany (source: Verkehrswacht, 2009)

Besides school education in groups, parents are asked to play important roles of traffic educations on their children, the instructions of children traffic education for parents are available (Elternheft, 2004), in which basic rules of behaviour for children on the road and its practical implementation are clearly explained. Furthermore, another important approach to children traffic education is "Safe routes to school programs", correct behaviour on the way to school, covering all possible modes including by foot, by bike, by bus and by car are included (Kühn et al. 2007).

On the contrary, traffic education in China is quite poor, there is no curriculum established in kindergartens, primary schools or secondary schools, drive schools are supposed to be the only approach of traffic education. However, on one hand, until the end of 2007, people with driver license take only 10% of the whole population, which means nearly 90% of the whole population in China have almost no knowledge about correct traffic behaviour at all; on the other hand, drive schools mostly focus on driving skills, few consideration for non-motorised is provided.

4.6 Traffic law enforcement

In Germany, traffic law StVO has been existed since 1934 and been modified and improved continuously, which includes basic regulations related to all traffic participants and meanings of all traffic signs and signals. However, there were no traffic laws regulating practices, procedures and norms of behaviour followed by motorists, cyclists and pedestrians in China until May 2004. Regulations named "City Traffic Regulations (1955)" and "Administrative Regulations (1988)" played relevant roles in this field, but vague and terse punishments for violators were relatively light, which leads to bad walking or driving customs and low discipline. Moreover, the recent traffic law still needs improvement, regarding pedestrian crossing traffic, for example, the meanings of signal indications such as Flashing Green and correct behaviour should be added.

In Germany, traffic law enforcement is mostly applied on motorised vehicles, for example, "Intelligent Speed Management (ISM)" plays an important role on traffic law enforcement recently, which mainly aims to restrict high speeds of motorised vehicles (Bauer and Seeck, 2004). Punishment by fine and subtraction of credits is also used in Germany. The new punishment category (Bußgeldkatalog) started form 01.02.2009 increased some punitive regarding the behaviour of lack of consideration of weak traffic participant on the road, for example, If turning vehicles don't consider pedestrians and pass through, the driver will be fined with €70 (€40 before) and two credits will be subtracted. Vehicles overtaking at zebra crossings will be fined with €80 (€50 before) and four credits will be subtracted (BMVBS, 2009). However, until now, pedestrian non-compliance is seldom punished in Germany.

So far as it is concerned, some measures of enforcement focusing on pedestrians have been taken in China, for example, traffic wardens are employed to patrol around the crossings to prohibit pedestrian non-compliance; pedestrians who violate signals will be warned or even fined. It was recorded that from March to May in 2006, 12,000 pedestrians and cyclists crossing on Red were fined and 20,000 were warned in Nanjing, China. However, enforcement on drivers' yielding behaviour is seldom applied in China until now.

4.7 Pedestrian safety problems at signalised intersections in China

Based on the comparison of pedestrian and driver behaviour, practice of traffic engineering, traffic education and law enforcement related to pedestrian traffic at signalised intersections in Germany and in China, pedestrian safety problem in China can be highlighted as follows.

(1) Mixed traffic creates a more complicated situation to be handled by pedestrians at signalised intersections in China.

Mixed traffic is the most significant characteristic of traffic situation in China, however, the situation is even more complicated at intersections. Threats to pedestrian safety come from different types of vehicles and bicycles with various dimensions and movement characteristics, such as passenger vehicles, buses, heavy vehicles, motorcycles, normal bicycles, electric bicycles etc., pedestrians' workload to judge updated situations and make correct decisions is higher than that in Germany when crossing at intersections.

(2) Low traffic discipline of traffic participants is the major problem endangers pedestrian safety.

- Pedestrians cross against signals quite often and consider their non-compliance blameless, pedestrians put themselves into risk situations but most of them are not aware.
- Turning vehicles always neglect pedestrians' right-of-way. It is pedestrians that give way to vehicles under most circumstances, which is opposite to the traffic law.
- Pedestrians and bicycles don't always wait at the designed areas, for example, pedestrians wait at the bicycle lanes, bicycles stop ahead of stop lines, occupying areas of pedestrian

crossings, so that additional pedestrian delay and conflicts come out.

(3) Non-friendly pedestrian facilities at signalised intersections deteriorate pedestrian safety and even induce improper behaviour of pedestrians and drivers which results in a vicious circle threatening pedestrian safety.

- Lack of detailed pedestrian accident data handicaps the most direct way to analyse pedestrian safety problems;
- Deficiencies of existing traffic guidelines increase difficulty for traffic planning, design and operation;
- For a long time, traffic planning, design and operation followed the notion of "vehicle-oriented", which put vehicle benefit on the highest position and neglect pedestrians' requirement, for example:
    - Long clearance distance due to improper location of crossings, large curb radii, exclusive bicycle lanes, lack of refuge islands in the middle leads to a problem of insufficient pedestrian clearance time.
    - Large number of motorised lanes to cross increases pedestrian exposure to risk, the asymmetrical gap distribution in different lanes induces pedestrian non-compliance, especially the attempt to cross "lane by lane".
    - Large curb radii result in high right turning speeds, together with insufficient shift distance of crossings, right turning vehicles are prone to fail to yield to pedestrians.
    - Waiting areas sometimes are insufficient, either at curb sides or at refuge islands.
    - Bicycles and pedestrians battle for space when they share signals, because crossing areas are not separated.
    - Improper signalisation such as too long cycle length and pedestrian red time, insufficient clearance time, improper control strategy of turning vehicles, etc. provokes pedestrian non-compliance and increases conflicts between pedestrians a and motorised vehicles.

(4) Lack of traffic education is the main reason for low traffic discipline of all road users in China;

(5) Traffic laws are new and with many deficiencies, meanwhile, the law enforcement on "driver yielding to pedestrians" is missing.

4.8 Conclusions

Generally speaking, pedestrian safety in China is much worse than that in Germany, especially at urban areas, pedestrian fatalities in China are about 135 times higher than those in Germany under the same motorisation level (possession of private cars per inhabitant).

Pedestrian non-compliance is recognised as the most important reason for pedestrian accidents in China. According to the empirical research, pedestrians arriving on Red are about three times more likely to cross against signals in China than in Germany. However, pedestrian attitudes towards crossing on Red are different: pedestrians in China consider their non-compliance blameless and would like to accept gaps during Red and prepare to have conflicts with vehicles when crossing on Red, while in Germany most pedestrians cross on Red only when they are quite certain that conflicting traffic is absent.

Low traffic discipline of vehicle drivers and cyclists deteriorate pedestrian safety, pedestrians easily lose right-of-way when they cross on Green, additional delay due to yielding to turning vehicles and space battle with bicycles increase the difficulty for pedestrians to finish crossing in designed Green time. Lack of traffic education, deficiencies of traffic laws and enforcement can be attributed to be the direct reason for low traffic discipline of all road users in China.

Regarding traffic engineering, pedestrian requirements are seldom taken into consideration when an intersection is designed and operated in China. “Vehicle-oriented” notion results in too long clearance distance and too long waiting time for pedestrians, which provokes pedestrian non-compliance easily; meanwhile, too smooth turning movements without any warning signals or signs for drivers is the main reason for conflicts between pedestrians and turning vehicles.

5. Measures to improve pedestrian safety

5.1 Introduction

5.1.1 Basic thoughts of measures

A "goal-objective-strategy-measure" framework (Figure 51) is built in order to search, sort and evaluate possible measures in a systematic way. The concept of "expected ped/veh conflicts" and "undesired ped/veh conflicts" related to objective 1 and objective 2 is defined as follows:

- Expected ped/veh conflicts: Possible conflicts between pedestrians and vehicles when they both comply with traffic regulations, these conflicts can be reduced by applying proper traffic engineering measures.
- Undesired ped/veh conflicts: Possible conflicts between pedestrians and vehicles when either or both don't comply with traffic regulations. These conflicts can be eliminated when pedestrians and motorists have high compliance.

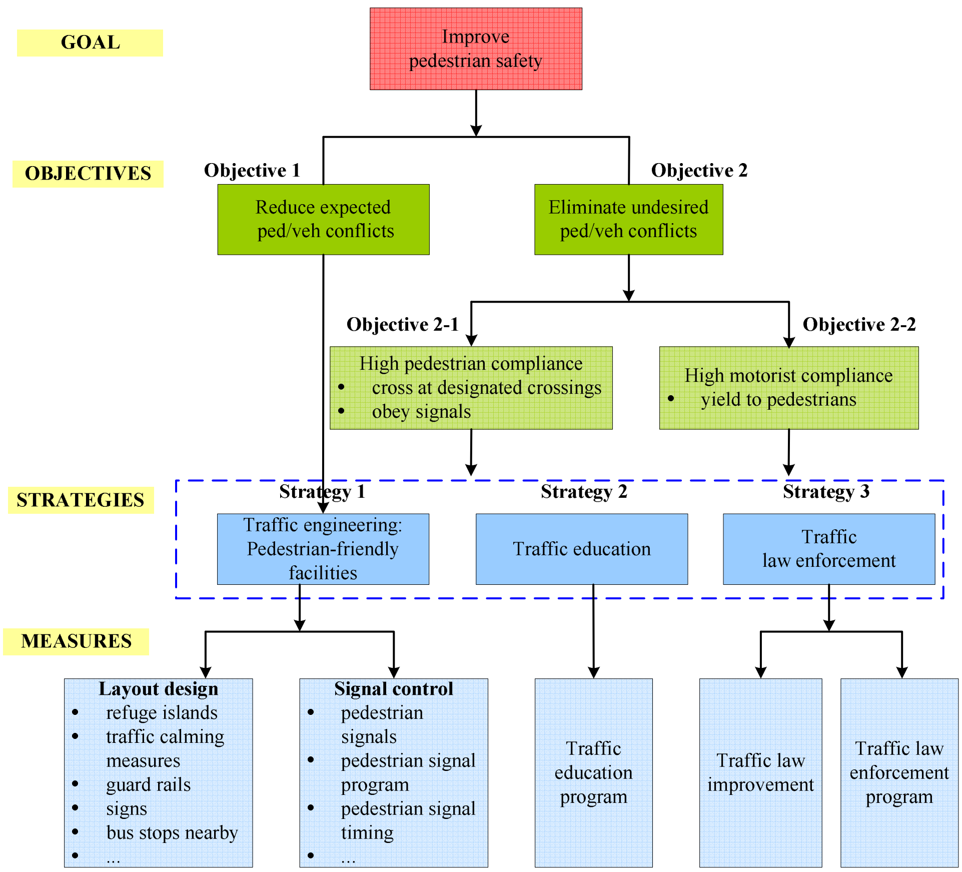


Figure 51: Goal-objective-strategy-measure framework

5.1.2 Methodology

Based on the conclusions of pedestrian safety problems in China drawn out in Chapter 4, targeted measures related to layout design, signal control, traffic education and law enforcement are searched and discussed in this chapter using following methodologies.

- Advantages and disadvantages of measures are mainly concluded by review of previous studies in various countries employing before-and-after approach, treatment-and-control approach etc.

- Applicability of traffic engineering measures (layout design and signal control) in China and the approaches of application are analysed through theoretical analysis, model calculation or empirical studies based on Chinese current conditions.

The main idea of model calculation is to predict pedestrian behaviour when applying different measures by using pedestrian behaviour model developed in chapter 4, such as pedestrian non-compliance model (cf. Eq.5) and interactions/conflicts model (cf. Eq.10).

Measures of effectiveness (MOEs) related to pedestrian behaviour, such as proportion or number of RW+EW, number of interactions/conflicts etc. can be calculated from the models and then compare the calculation results to evaluate the effect of measures.

- Measures of traffic education and law enforcement for China are proposed based on a combined consideration of experiences from other advanced countries and current conditions in China.

5.2 Measures of layout design

5.2.1 Basic requirements of pedestrian-friendly layout design

Some basic requirements of pedestrian-friendly layout design at signalised intersections are listed as follows:

- The location of crossings should follow the majority of pedestrian crossing stream, long detour must be avoided;
- Make crossing distance as short as possible without decreasing safety level of the whole intersection;
- Ensure high visibility of pedestrians and vehicles. Street furniture, poles, vegetation, parking cars etc. shouldn’t block the sight of pedestrians and motorists;
- Ensure lower vehicle speeds when passing crossings;
- Make traffic signs be visible und understandable for both pedestrians and motorists;
- Illumination, drainage and antiskid of crossing have to be paid attention;
- Take special consideration for the disabled pedestrians.

5.2.2 Refuge islands

Pedestrian refuge islands have been demonstrated to be able to decrease the percentage of pedestrian crashes significantly (Harkey and Zegeer, 2004), its advantages include:

- Refuge islands are likely to direct more pedestrians to cross within the crossing (Huang,2000).
- Refuge islands enable pedestrians to focus on one direction of traffic at one time and provide pedestrians with a better view of oncoming traffic and allow drivers to see pedestrians clearly (Zegeer, 2001; Bacquie, 2001).
- A safe place in the middle of the street is provided for pedestrians who can't finish crossing in one go.
- More flexible signalisation can be applied when refuge islands exist, for instance, the clearance time can be shortened, longer pedestrian green time is available (RilSA, 2003).

However, there are also some negative results of setting up refuge islands. For instance, an early study undertaken in London (Lalani, 2001) concluded that the provision of refuge islands surprisingly increased pedestrian collisions. Baass (1989) reviewed that a German study in seven cities showed 65% of all pedestrian collisions at signalised intersections happened on crossings with median islands. Such negative effects are probably due to pedestrian non-compliance caused by the existence of refuge islands and the different signal states on two halves. Firstly, the crossing difficulty is significantly reduced since the crossing distance is decreased and only one way traffic has to be concerned; secondly, pedestrians intend to have successive crossing; thirdly, if pedestrians wait on Red see the other half displays Green, they may cross on Red in order to catch Green of the other half.

Considering the advantages and disadvantages of refuge islands, their establishment can be beneficial under certain conditions and harmful under others (Hubbel, Roth, Clark, 1999), as listed in Table 14.

Table 14: Beneficial and harmful conditions to establish refuge islands

beneficial conditions	harmful conditions
• wide, two-way streets (four lanes or more) with high traffic volume and high travel speed; • wide streets where the elderly, people with disabilities, and children cross regularly; • wide streets where protected left-turn phasing is used; • main streets intersected with minor streets where the traffic demand is too low, insufficient pedestrian crossing time or undue vehicle delay can be avoided when refuge island is established together with proper signalisation.	• narrow streets; • refuge islands with substandard width; • streets with high turning volume of heavy vehicles to access; • turning space is insufficient that vehicles are easily drive into the island; • areas where the presence of refuge islands will severely hamper snow-plowing.

Application of refuge islands in China

A “theoretical before-and-after analysis” is carried out at one crossing in Shanghai (S(3,2,0)). Together with the newly established refuge island, separate signalisation at successive crossing is applied, so that pedestrian clearance time can be shortened and longer green time is available, as shown in Figure 52. Detailed calculation can be found in Appendix D.

Measures of effectiveness (MOEs) include:

- proportion of pedestrians crossing on Red (RW+EW)
- undesired conflicts between pedestrains and vehicles

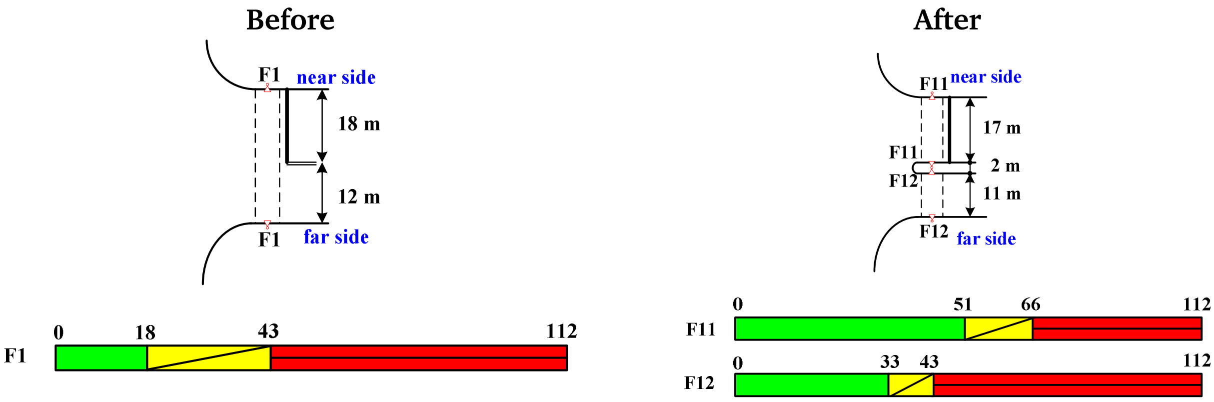


Figure 52: Pedestrian signal programs before and after

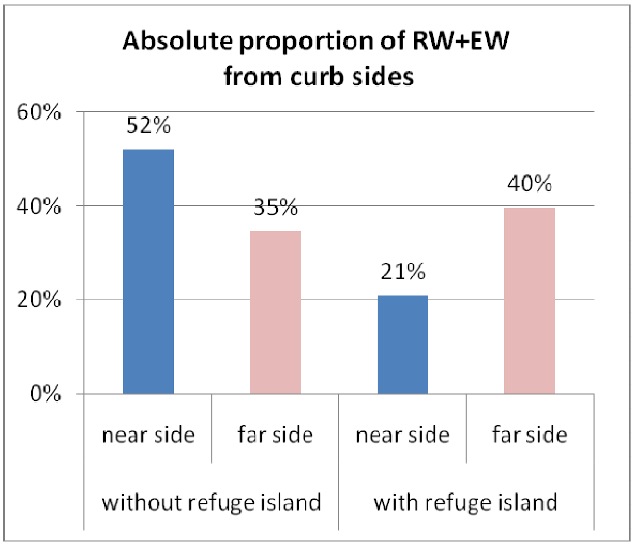


Figure 53: Absolute proportion of RW and EW from curb sides

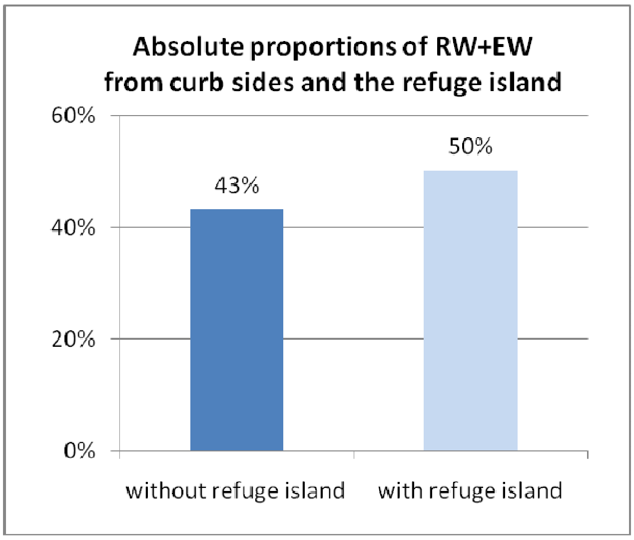


Figure 54: Absolute proportion of RW and EW from curb sides and the refuge island

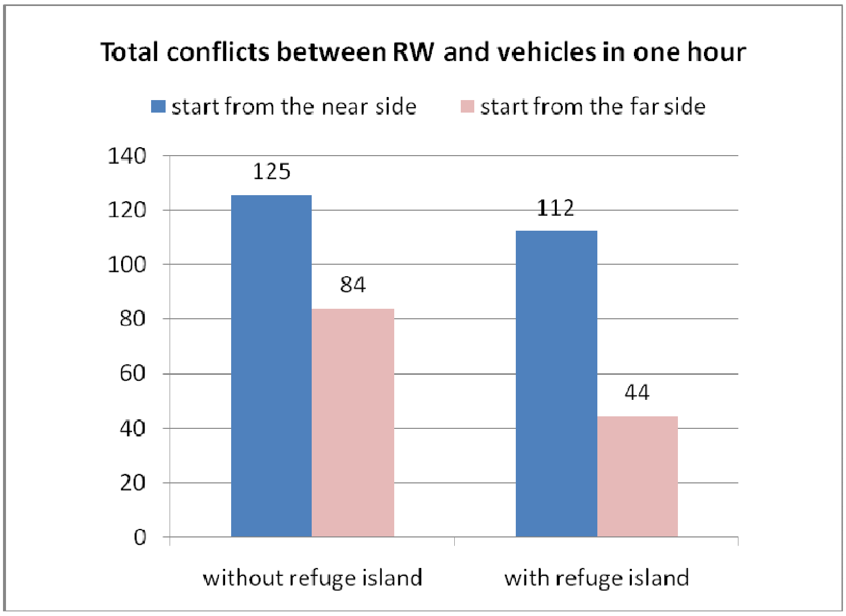


Figure 55: Total number of conflicts between RW and vehicles in one hour

The results shown in Figure 53, 54, 55 indicate that pedestrian signal violation significantly decreases at the near side half where green time significantly extends, but the total number of pedestrians who cross on Red increases because pedestrians also violated signals at the refuge island. However, the establishment of a refuge island is proved to improve pedestrian safety in this case, since the number of conflicts between RW and vehicles reduces by 11 % and 47 % in two directions respectively.

The following issues have to be taken into account regarding establishment of refuge islands in China:

- "Lack of space " is the most common excuse for not establishing refuge islands in China since large numbers of approaches and exits at intersections for motorised traffic are prior designed and constructed, therefore, a trade-off between capacity of motorised traffic and pedestrian safety have to be made. When the total width of motorised lanes exceeds 15 m, a refuge island is required.
- The area of refuge islands should be sufficient to accommodate pedestrians. RilSA (2003) has regulated the minimum width of refuge islands is 2.5 m, also it has mentioned that "too small refuge islands may have to be expanded, even at the expense of reducing carriageway width or the number of lanes". However, a minimum width of 1.8m must be satisfied in China, on one hand, smaller personal space is required by Chinese pedestrians; on the other hand, the design length of bicycles has to be satisfied. If necessary, the area can be enlarged by extending the length of refuge islands or applying staggered crossings (Figure 56).
- Signalisation at successive crossings has to be considered, more details see 5.3.4.1.
- Marked refuge islands with protections at the ends or raised refuge islands can both be used, the former one is more convenient for the disabled, wheelchairs and bicycles; when the latter is used, the curb ramps should be built.
- The illuminated bollards are useful to minimize the potential of drivers running into the refuges in darkness.

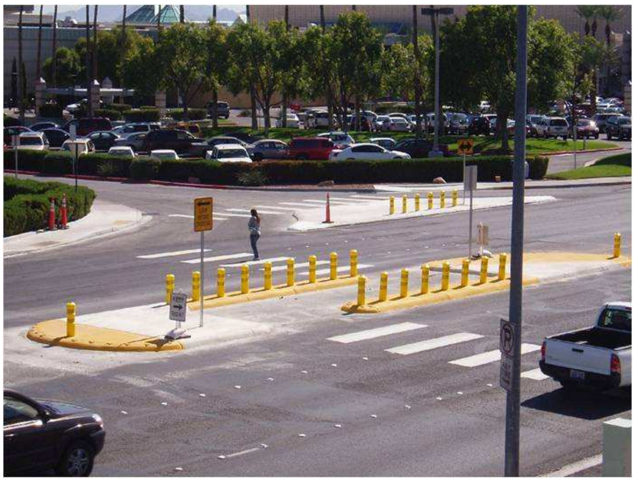


Figure 56: An example of staggered crossing in Las Vegas , the U.S.

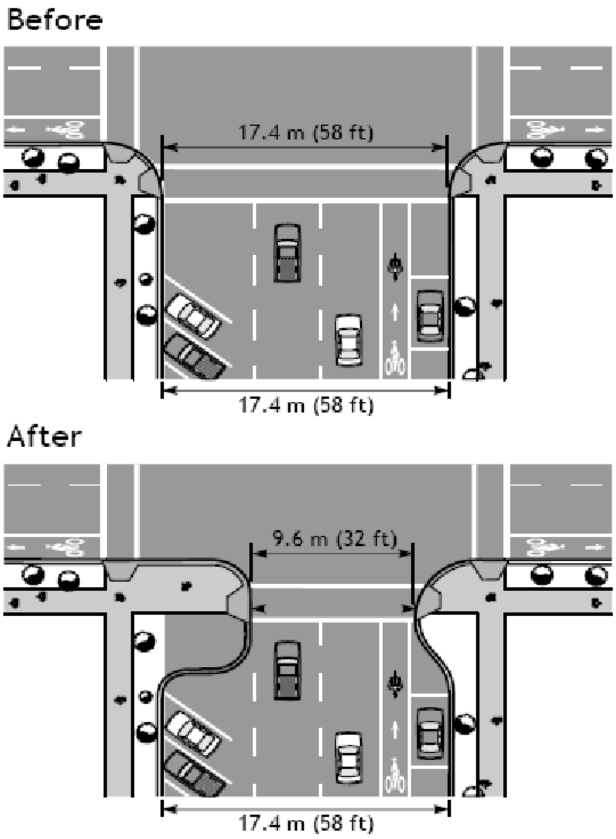
5.2.3 Traffic calming measures

Traffic calming measures may benefit pedestrians who are crossing the street by slowing down vehicle traffic, shortening crossing distances, enhancing motorist and pedestrian visibility and encouraging drivers to yield to pedestrians (Huang, 2001). Traffic calming measures can be applied at intersections include curb extension, reduced curb radii, raised crossings and raised intersections. In the previous studies, all or some of the measures below is collected as the measures of effectiveness (MOEs):

- driver behaviour of yielding to pedestrians
- vehicle speed
- utilization of designated crossings
- pedestrian accidents with vehicles

Curb extension

Curb extension , examples are shown in Figure 57 and Figure 58, intends to slow vehicles down and increase the likelihood that motorists will notice pedestrian crossing and yield to them. Also it was thought that curb extension would motivate pedestrians to cross at the crossing because shorter crossing distances are provided (FHWA, 2006).



(a) Oakland, CA (source: mtc, 2009)

(b) Venice, CA (source: mtc, 2009)

Figure 57: Reduction of crossing distance through curb extension (source: FHWA, 2006)

Figure 58: Examples of curb extension in the U.S.

Case studies employing "before-and-after approach" in four crossings in two cities (Cambridge and Seattle) and "treatment-and-control approach" in eight crossings in another two cities (Greensboro and Richmond) were carried in the U.S. (Huang and Cynecki, 2001), the effect of curb extension appeared different from each other, and even some unexpected results appeared. For example, more pedestrians crossed at the designated crossings after curb extension was established, though the increase was not statistically significant in Cambridge, while it was the other way round in Seattle, significantly less pedestrians cross at the designated crossings after curb extension. Vehicle speeds and motorist yielding behaviour made no big differences in most of the comparable crossings.

Reduced curb radii

Reduced curb radii can reduce pedestrian crossing distance (the increase of crossing distance when curb radii increase from 10 m is shown in Figure 59), decrease vehicle turn speeds and improve pedestrian visibility to vehicle drivers.

However, disadvantages of reduced curb radii also exist, for instance, the small radius make it harder for trucks and other larger vehicles to turn without the rear wheels mounting the corner curb, which can lead to damage of the sidewalk area. To avoid this problem, some drivers swing into opposing lanes of traffic, which can cause traffic delays (FHWA, 2006). Vehicular capacity at intersection will be decreased if the volume of right turning is high.

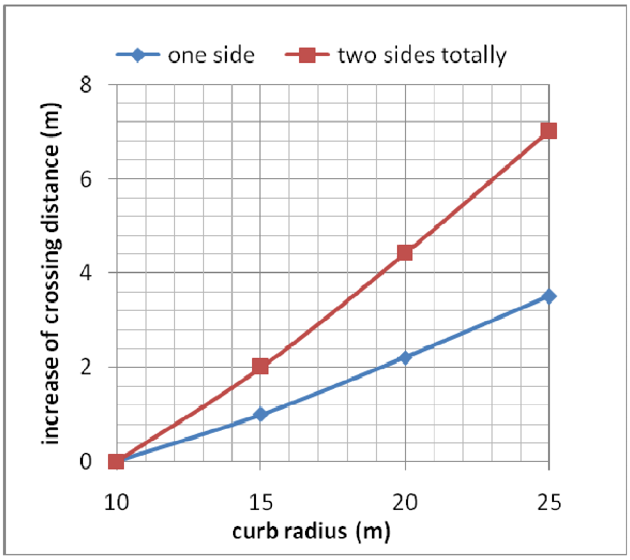


Figure 59: Increase of crossing distance when curb radii increase from 10m

Raised crossings

An example of raised crossing in Helsinki, Finland is shown in Figure 60. According to Zegeer et al (2001) and Sanca (2002), the effect of raised crossings is a reduction in vehicle speed and an increase in vehicles giving way to pedestrians, both of which give a safety benefit to pedestrians. However, the effect of raised crossings appeared different from each other. For example, Driver behaviour collected in Durham (Huang, 2001) showed that motorists stopped for 79.2% of pedestrians at the raised crossing with an overhead flasher, while stopped for only 31.4% at the control sites without raised crossings, and the 50th percentile vehicle speed was 6.5 to 19.3 km/h lower at the treatment site. While studies in Montgomery County (Huang, 2001) presented no positive results, yielding behaviour made nearly no difference at raised crossings and at normal crossings, and the reduction of 50th percentile speed was not statistically significant either.

Figure 60: An example of raised crossing in Helsinki, Finland

Raised intersections

Before and after data were collected at one raised intersection in a residential area in Cambridge, Massachusetts, it was found that the percentages of pedestrians who crossed in the crossing increased by 38.3% in the after period (Huang, 2001).

Summary of traffic calming measures

A comprehensive comparison of four traffic calming measures which can be used at signalised intersections is listed in Table 15.

Table 15: Comparison of four traffic calming measures

Traffic calming measures		Curb extension	Reduced curb radii	Raised crossing	Raised intersection
advantages	Reduce crossing distance	+	+	0	0
	Reduce vehicle speeds	0/+	0/+	+	+
	Encourage drivers to yield to pedestrians	0/+	0/+	+ (+)	0/+
	Encourage pedestrians to use the crossing	-/0	0/+	+	0/+
disadvantages	Reduce vehicular capacity	+(+)	+(+)	0/+	0/+
	Impede the access of other traffic participants (e.g. bicycles, buses, trucks, emergency vehicle, etc.)	+ +	+ +	0	0
	Hinder street cleaning and snow plowing	+	+	0	0
	Affect drainage	0	0	+	+
cost	Newly built	+	+	+	+ +
	Rebuilt	+	+ +	+ +	+ + +
Feasibility in China		**+**	**+ +**	**+ +**	**0**
Note: +: low; + +: moderate; + + +: high; 0: no effect; -: negative effect					

Application of traffic calming measures in China

Theoretically, the traffic calming measures are beneficial for improving pedestrian safety, but according to the practical experiences, it can be concluded that traffic calming devices are not a panacea guaranteed to improve conditions for pedestrians. These devices by themselves cannot ensure that motorists will slow down and yield to pedestrians, nor pedestrians will cross at the designed crossing (Huang, 2001).

The effect is mainly influenced by the acceptance of both drivers and pedestrians. Similar trials can be done in China, but the following issues need to be considered:

- Curb radii can be reduced in many intersections, since most of the existing radii are far bigger than actually being required.
- Curb extension can be used under the following conditions:
    - where there is a parking lane
    - residential areas or neighbourhood shopping areas, where pedestrian activities are frequent and vehicle volume is relatively low
    - routes without high volume of turning traffic of buses and heavy vehicles
    - routes used mostly by school children and the elderly;
- Curb extensions mustn't extend into travel lanes, bicycle lanes, or shoulders (curb extensions should not extend more than 1.8 m from the curb) (Huang, 2001).

5.2.4 Guard rails

The main purpose of guard rails in the forms of chains, fences and other similar devices is to channel pedestrians to cross at designated crossings (Gehl, 2004), the examples of guard rails erected along the side walk and at staggered crossings are shown in Figure 61.

(a) Guard rails along the side walk
(source: Alpharail, 2009)

(b)Guard rails at staggered crossing
(source: the UK Highway Code, 2009)

Figure 61: Examples of pedestrian guard rails

The Transportation Research Group, University of Southampton contributed a lot to the research on pedestrian guard rails. In the final report by Zheng and Hall (2006), the effectiveness of guard rails at different types of sites, such as at mid-blocks and intersections, at transportation interchanges, schools, etc. has been studied. The measures of effectiveness (MOEs) include:

- utilization of pedestrian crossings
- pedestrian accidents

The results pointed out that at pedestrian mid-block crossings, installation of guard rails can effectively channel pedestrians to the crossing, while the effectiveness at intersections is insignificant, since pedestrian crossings at intersections are usually in the direction of the movements of majority pedestrians, even at sites without rails. Also it concluded that there were safety benefits in installing guard rails both at mid-block and intersection crossings, since pedestrian accidents are fewer at sites with rails. Similar results was also concluded in previous studies by Older and Grayson (1976), Simmonds (1983) etc.

Guard rails erected at the intersections can ensure pedestrian safety in the following aspects:

- Prevent pedestrians from crossing at the most risky locations, 50m or less than 50m near to the crossing at signalised intersections (Grayson,1987; Preston, 1989);
- Prevent pedestrians from crossing at forbidden arms of intersections out of safety or other reasons (Department of Transport, 1981).

Application of guard rails in China

- Guard rails must be erected at intersections with irregular configuration, where pedestrians are forbidden to cross at some arms.
- Movable barriers operated by traffic wardens (a traffic warden is a member of civilian staff employed by the police force to assist in regulating the flow of traffic, defined in Road Traffic Act 1960, Britain), simultaneously moved with pedestrian signals, can be deployed to reduce pedestrian non-compliance.
- The idea is that fixed guard rails can be erected around the corner excluding the access to the crossing and the movable guard rails at the access to the crossing, which can be operated by a traffic warden. "Traffic wardens pull a rope across the pavement when the pedestrian's red light is on, to keep back pedestrians and bicyclists. When the light switches to green, the rope is pulled away", which is already put into practice already in Taixing from June 2009 (China Daily, 2009).
- Guard rails must be provided on refuge islands of staggered crossings.
- The negative impacts of guard rails on urban road design and cityscape has to be taken into consideration.
- Finally, more risky behaviour such as jumping over the railing or moving underneath exists, therefore, the forms and height of guard rails should be considered.

5.2.5 Signs

Signs are used to inform road users of regulations, warn them of dangerous situations and also provide additional information for other signs or for signals. General categories of signs to prompt pedestrians and motorists are listed in Table 16, adapted from MUTCD (2003). In, Figure 62 pedestrian signs used in the U.S. are listed.

Table 16: Signs at intersections to prompt pedestrians and motorists

	Signs to prompt pedestrians	Signs to prompt motorists
Regulatory signs	• Pedestrians use crossing • Use of pedestrian push button	• Speed limitation • Turning vehicles yield to pedestrians • Not turn on Red
Warning signs	Pedestrian watch for turning vehicles	-
Informational signs	Meanings of pedestrian signals (cf. Figure 63)	-

Figure 62: Pedestrian signs in the U.S.

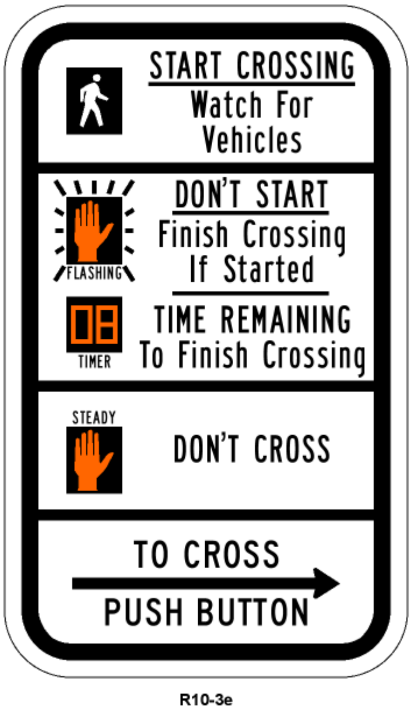


Figure 63: Example of informational signs

As regulated in StVO in Germany, there are five basic types of signs:

- warning signs (Gefahrzeichen)
- recommendation signs (Richtzeichen)
- regulation signs (Vorschriftzeichen)
- signs of transportation facilities (Verkehrseinrichtungen)
- symbols(Sinnbilder) and additional signs(Zusatzzeichen).

Relevant pedestrian signs regulated in StVO are listed in Figure 62, however, most of them are used at sidewalks, but not at crossings.

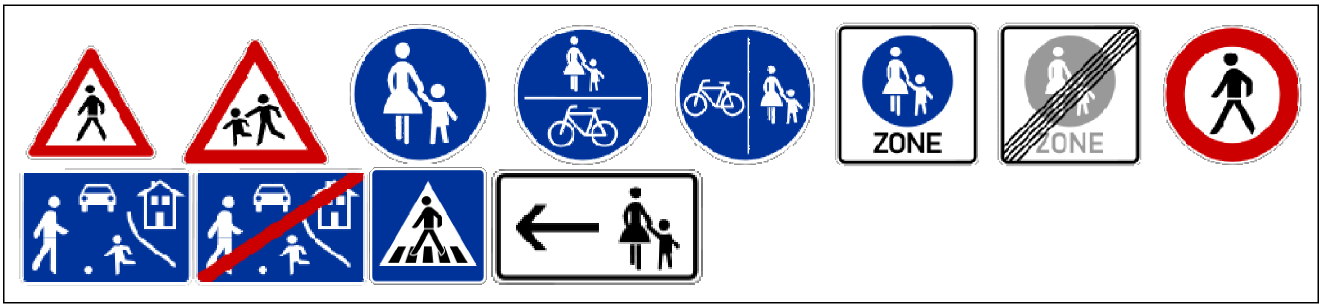


Figure 64: Pedestrian signs in Germany (StVO)

Innovated signs are widely studied in the U.S., for example, the “in street yield to pedestrian signs” (Figure 65) were reported to have a significant effect on driver yielding behaviour in Miami, since the percentage of drivers yielding to pedestrians increased from 19% to 71%. Besides, pavement marking to prompt pedestrians to watch for oncoming traffic is proved to be useful (Figure 66).

Figure 65: In street yield to pedestrian signs

(source: Fortunada, 2009)

Figure 66: Pavement marking in UK

(source: Tfhrc, 2009)

Furthermore, signs must be with high visibility and legibility, too many signs at one site must be avoided, because it may contribute to sign pollution and lose effectiveness over time (Harkey and Zegeer, 2004).

Application of traffic signs in China

- Some signs used in the U.S. can be deployed in China as well, for example, the signs explaining meanings of pedestrian signals and signs to prompt turning vehicles to yield to pedestrians.
- Forms, texts and locations of signs are to be determined by certain local conditions, field studies in local sites is necessary in order to find out the most proper way to have high acceptance.
- Pavement marking is an efficient way to prompt pedestrians to pay attention to oncoming turning vehicles before crossing.

5.2.6 Consideration of transit stops nearby

Non-exclusive right-of-way transit system

It mainly refers to the normal city bus system with bus stops located at the sidewalk. One type of pedestrian accidents nearby bus stops is that pedestrians step into the street in front of a stopped bus and are struck by vehicles moving in the adjacent lane (Zegeer, 1998), it happened mostly because the visibility between pedestrians and oncoming vehicles was blocked or pedestrians crossed against the signal to catch the bus.

One possible solution is to relocate the involved bus stop to the far side. It encourages pedestrians to cross behind the bus instead of in front of it so that both pedestrians and oncoming vehicles are able to observe each other easily and clearly. Based on the studies in Miami and San Diego (Berger, 1975), the relocation of bus stops to the far side virtually eliminated the undesired behaviour of crossings in front of the bus.

Exclusive right-of-way transit system,

It mainly refers to the tram system or Bus Rapid Transit system with bus stops mostly in the middle of the road. However, it brings more safety problems to pedestrians since all of the passengers have to cross the street.

Under most circumstances, pedestrian crossings and tram stations at intersections are integrated designed in Germany, as shown in Figure 67. The crossing is divided by two refuge islands into three parts and the middle part include transit stops and transfer areas, fences are installed along the tram stations to channel pedestrians to cross at designated crossings. Signal control of the middle part is determined by the arrival and departure of the transit vehicles, flashing yellow signals are also used to warn pedestrians of the coming transit vehicles.

(a) Darmstadt, 2008

(b) Darmstadt, 2008

Figure 67: Examples of integrated design of tram stations and pedestrian crossings in Germany

Suggestion with reference to transit stops in China

- When bus passenger volume is high, it is better to locate bus stop at the far side and make it as near to the crossing as possible.
- Guard rails along the sidewalk with a gap at the bus stop can be used to guide pedestrians to cross at the designated crossing after they get off or before they get on.
- Design of BRT stops in the middle of the road can follow the German methods mentioned above.

5.2.7 Summary of measures of layout design

The ten measures discussed above (Section 5.2.2~5.2.6) are summarised from aspects of effects on improving pedestrian safety (acceptance level is considered), influence on capacity of motorised traffic and cost of construction, finally the feasibility of such measures in China is concluded, as listed in Table 17. The acceptance level is expected to be high when traffic education is popularized and traffic law enforcement works.

Regarding the cost of construction, the cost of rebuilt is normally higher than the newly built, the additional cost of rebuilt is indicated in the brackets.

Table 17: Summary of measures of layout design

No.	Measures	Improve pedestrian safety (when acceptance is high)	Influence on capacity of motorised traffic	Cost of newly built (rebuilt)	Feasibility
1	Refuge island	+ + (+)	0 / -	+ + (+)	+ + +
2	Curb extension	+ (+)	-	+ + (+)	+
3	Reduced curb radii	+ (+)	-	+ (+ +)	+ +
4	Raised crossing	0/+	0 / -	+ +(+ +)	+
5	Raised intersection	0/+	0 / -	+ +(+ + +)	0
6	Guard rails	+ (+)	0 / +	+ + (+)	+ + +
7	Transit stops at far side	+ +	0 / -	+ (+)	+ +
8	Integrated design of transit stops and crossings	+ +	0	+ + (+)	+ (+)
9	Signs (pavement marking) to prompt pedestrians	+ +(+)	0	+	+ +
10	Signs to prompt motorists	+ (+)	0 / -	+	+ +

Note: +:positive low; + +: positive moderate; + + +: positive high; 0: no effect; -: negative effect

5.3 Measures of signal control

5.3.1 Basic requirements of pedestrian- friendly signal control

Some basic requirements of pedestrian-friendly signal control at signalised intersections are listed as follows.

- Signals must be located with high visibility, if the street is too wide, pedestrian signal heads should also be established on the refuge islands.
- Meanings of pedestrian signals should be made clear to the road users.

- Shorten pedestrian waiting time, when possible, time-dependent signal program or traffic actuation (pedestrian actuation and/or vehicle actuation) is recommended in order to avoid pedestrians to wait in front of empty streets for long time.
- Provide pedestrians with adequate crossing time, especially sufficient clearance time.
- Reduce conflicts between pedestrians and turning vehicles.
- Avoid too complicated signalisation.
- Use accessible pedestrian signals (such as audible tones, verbal messages, vibrating surfaces) for the sake of the disabled.

5.3.2 Pedestrian signal indications

5.3.2.1 Signal indications of pedestrian clearance time

Red vs. Yellow

Düsseldorf is the only city in Germany using Yellow signal for pedestrians, there is a yellow bar in the middle of the signal head displaying pedestrian clearance time. While in other areas of Germany, only Red and Green signals are used for pedestrians and the first several seconds of Red is used for pedestrian clearance.

Discussion of “two-colour-signal head” or “three-colour-signal head” for pedestrians started from 1970s in Germany. For example, Von Stein (1976) advocated Yellow signal as the pedestrian clearance signal, because of the following advantages: (1) Red signal can have a clearer meaning of “stop”, which can be easily understood and accepted by pedestrians; (2) To make turning drivers know it is clearance time of pedestrians, but not the wrong behaviour of pedestrians violating signals etc. Meanwhile, the number of pedestrian accidents was lower in Düsseldorf than in other comparable cities in Germany, such as Frankfurt and Köln.

Following the “Düsseldorf Model”, a trial of Yellow signal for pedestrians was carried out in two intersections in Aachen (Germany) in 1989. The results showed that number of pedestrians crossing on Red slightly decreased in both intersections after the Yellow signal was used, while the conflicts between pedestrians and vehicles differed a lot, at one intersection the conflicts sharply decreased while at the other one conflicts significantly increased at some arms.

A study taken in the U.S. by Zegeer et al. (1982) found that a “steady DON'T WALK message” for the clearance and pedestrian prohibition intervals provided no improvement over the “flashing DON'T WALK”. A “DON'T START message (steady yellow)” resulted in a significant reduction in pedestrian violations and conflicts compared with the “flashing DON'T WALK”. However, the “DON'T START message” is similar to Yellow signal in its function, but the message could provide more straightforward information for pedestrians.

Investigations of some typical crossings at signalised intersections have been taken in Frankfurt and in Düsseldorf in this study and pedestrian behaviour has been analysed.

The measures of effectiveness (MOEs) include:

- relative proportion of LW
- failure rate of LW: proportion of LW who don’t finish crossing when Green of conflicting traffic starts
- pedestrian clearance speed
- proportion of LW involved in conflicts and in very risky situations (PET< 4 s)

The results are shown in Table 18, Table 19 and Table 20.

Table 18: Comparison of pedestrian behaviour at crossings with(out) Yellow signal

		Red	Yellow		Red	Yellow	
from the curb side	MOEs	F(3,2,1) (N=9)	D(3,2,1) (N=5)	significance (α=0.05)	F(3,3,1) (N=14)	D(2,2,1) (N=13)	significance (α=0.05)
	relative proportion of LW	33%	56%	Y	57%	92%	Y
	failure rate of LW	0%	20%	Y	13%	75%	Y
		Red	Yellow		Red	Yellow	
from the refuge island	MOEs	F(3,2,1) (N=8)	D(3,2,1) (N=8)	significance (α=0.05)	F(3,3,1) (N=87)	D(2,2,1) (N=3)	significance (α=0.05)
	relative proportion of LW	60%	63%	N	70%	100%	N
	failure rate of LW	20%	63%	Y	82%	67%	N

Note: Y: statistically significant under the significance level of 0.05;
N: not statistically significant under the significance level of 0.05;

Table 19: Comparison of pedestrian clearance speed at crossings with(out) Yellow signal

	Red	Yellow		
from the curb side	F(3,2,1) (N=9)	D(3,2,1) (N=5)	difference in speeds	significance (α=0.05)
	1.39 m/s	1.85 m/s	0.46 m/s (increase by 33%)	Y
	Red	Yellow		
from the refuge island	F(3,2,1) (N=8)	D(3,2,1) (N=8)	difference in speeds	significance (α=0.05)
	1.10 m/s	1.63 m/s	0.53 m/s (increase by 48%)	Y

Table 20: Proportion of LW involved in conflicts and very risky situations (PET< 4 s)

signal	crossing	sample size of LW	conflicts	PET<4 s
Red	F(3,2,1)	8	38% (at entrance)	0%
	F(3,3,1)	41	0%	5% (at entrance)
	F(3,3,1)	22	0%	77%(at exit)
Yellow	D(3,2,1)	8	0%	38% (at exit)
	D(2,2,1)	15	0%	0%

The results show that:

- There are significantly more LW starting from the curb side on Yellow; the results is not statistically significant for pedestrians starting from the refuge island possibly due to the too small sample size and the effect of refuge islands on pedestrians' intention of successive crossing .
- Crossing speed of LW is significantly higher when Yellow signal exists.
- Less LW are involved in conflicts or very risky situations when Yellow signal exists.

The effect of Yellow signal on pedestrian safety is mixed. On the one hand, the additional Yellow signal provides pedestrians with clear information, they won't feel worried when they see Yellow if they are still on the crossing, and pedestrians are more aware of the situations that conflicting traffic will start as soon as Yellow ends, since less pedestrians are involved in the very risky situations; however, on the other hand, it encourages pedestrians to start to cross during clearance time, which brings potential risks.

Flashing Green with Countdown signals

Countdown signals are widely applied in the U.S. and the MUTCD (2003) provides a national standard on Countdown Pedestrian Signals (CPS) during pedestrian clearance time, which is regulated as "the display of the number of remaining seconds shall begin only at the beginning of the pedestrian change interval, until the termination of pedestrian change interval".

The effectiveness of countdown signals varies from different conditions. Case studies at San Francisco (Ragland et al., 2008) and Miami-Dade (Ellis and Van Houten, 2008) recognised pedestrian countdown signals as one of "cost-effective measure". A study of 579 interactions in San Francisco found that the number of pedestrian injury collisions decreased by 22% and the proportion of pedestrians who finished crossing during red phase and who ran or aborted crossing decreased from 45% to 34%. Similar results are also pointed out by Keegan (2003) in Dublin.

However, some negative effects of countdown signals exist, Huang and Zegeer (2000) found that pedestrians' compliance of signals decreased from 59% to 47% according to the investigation in Lake Buena Vista, for more pedestrians may decide to "run for it" when they arrive on Flashing Don't Walk (FDW) if they see how many seconds are left.

In China, countdown signals are also applied in some cities with Flashing Green during clearance time. Empirical studies have been taken at four crossings in Shanghai (China), the results listed in Table 21 presented that:

- the proportion of LW makes no significant difference at crossings with or without countdown signals, nearly all pedestrians start to cross during Flashing Green;
- a paradox exists that pedestrian clearance speed is faster at crossing with countdown signals, but more pedestrians can't finish crossing before pedestrian Red starts.
- less pedestrians are involved in conflicts at crossings with countdown signals.

Table 21: MOEs at crossings with/without countdown signals in Shanghai (China)

crossing		sample size	relative proportion of LW	LW don't finish crossing before Red	clearance speed	proportions of pedestrians with conflicts
With countdown	S(4,2,0)	20	90%	89%	1.87 m/s	10%
	S(4,3,0)	35	100%		-	29%
Without countdown	S(2,2,0)	96	98%	61%	-	48%
	S(4,3,1)	27	100%	78%	1.74 m/s	37%
Significance (α=0.05)			N	Y	Y	Y

Note: Y: statistically significant under the significance level of 0.05;
N: not statistically significant under the significance level of 0.05;

Based on the previous studies by the Metropolitan Transportation Committee in California and some other studies (e.g. Zegeer,2000; Keegan,2003; Markowitz, 2006; Arhin, 2007; Ragland et al.,2008; Ellis and Van Houten, 2008; etc.), the advantages and disadvantages of countdown signals during pedestrian clearance time can be summarised in Table 22.

Table 22: Advantages and disadvantages of countdown signals during pedestrian clearance time

advantages	disadvantages
• Provide pedestrians with information of remaining crossing time, which can be easily understood by all age groups; • Induce higher clearance speeds; • Reduce number of conflicts between pedestrians and vehicles; • Increase pedestrian perception of safety.	• May encourage pedestrians to start during clearance time, even at the last few seconds; • Pedestrians can't correctly judge when to cross and in which speed to cross is safe, proportion of pedestrians who can't finish crossing before Red increases; • Not accessible to pedestrians with impaired vision; • Inconsistent with traffic actuation; • Drivers may start before they have Green when they see pedestrian countdown time reaches zero, but it has been found not a problem by Markowitz (2006).

Countdown from the beginning of Green

Actually, countdown started at "WALK" indication also existed in the U.S. before 2003 (Lalani, 2001), but only countdown for clearance time is recommended in the MUTCD, one reason could be "Some suppliers start countdown from the beginning of pedestrian Green, some starts from pedestrian clearance time, which make pedestrians confused".

Investigations in Shanghai in the empirical research also contains one crossing with countdown signal from the beginning of pedestrian Green, three seconds of all-Red follows after the countdown signal displays zero. Actually there is no clearance period indicated by signals. It has been seen that pedestrians enter the crossing even at the last few second of the green time, around 25% of pedestrians who start to cross on Green (GW) couldn't finish crossing before Red starts in a cycle.

However, in this case, the oncoming traffic of the next phase is left turning vehicles, three seconds all-Red plus entering time of left turning vehicles is enough for pedestrian clearance, but if the entering flow starts from the same entrance, the situation for pedestrians would be more dangerous.

Recommendations of signal indication for pedestrian clearance time in China

- Display of pedestrian clearance time is necessary. Flashing Red is recommended because of its clearer warning effects than Flashing Green. In order to have a high level of pedestrian acceptance and compliance, treatment of traffic education and traffic law enforcement is required. For example, signs explaining meanings of traffic signals can be erected nearby or traffic wardens can be employed to guide pedestrians to behave correctly.
- Countdown signals during clearance time can be used, but aggressive behaviour of crossing at the last few seconds must be prohibited.
- Countdown signals starting from the beginning of Green without displaying clearance time is harmful and should be avoided, because it's difficult for pedestrians to judge when it is still safe to cross, what's worse, pedestrians may think it is safe since they cross on Green, even when they start at the last few seconds.

5.3.2.2 Countdown signals indicating remaining red time

By providing accurate information of remaining waiting time, pedestrian overestimation of "how long they have waited" and uncertainty of "how long they still have to wait" can be eliminated, which can reduce pedestrian non-compliance partly.

A trial in France (Druilhe, 1987) found that the supplementary information provided to pedestrians about how long they have to wait was beneficial in that it tended to make long waiting times a little more bearable. Keegan (2003) carried out a before-and-after study in Dublin, and he found that pedestrians who start to cross on Green increased from 65% to 76% after the countdown signals were installed. A recent study done by Celikkan et al. (2008) in Hamburg(Germany), where a pilot project of countdown signals was taken, found that countdown indications can reduce proportion of pedestrians who cross on Red (from 21% to 16.7%), and it was highly accepted by pedestrians, particularly the elderly.

However, some early studies showed negative results as well, for example, as noted by Baass (1989), this information might also lead to increase of non-compliance when the indicated waiting times are "too long".

Application of countdown signals indicating remaining red time in China

Countdown signals indicating remaining red time are used in some cities in China already, but pedestrian non-compliance doesn't change much. It is possibly because, on the one hand, pedestrians with low traffic discipline easily ignore Red signal, on the other hand, the displayed remaining waiting time is so long that pedestrians are reluctant to wait.

Pedestrian red countdown can be installed, but the signal program must ensure that the duration of red time is less than the threshold of pedestrian waiting time (e.g. 60 s), otherwise it will enlarge the negative effects on pedestrian signal violation.

5.3.3 Parameters of pedestrian signal program

5.3.3.1 Maximum pedestrian red time

Pedestrian level of service (LOS) at signalised intersections is evaluated by pedestrian average waiting time according to HBS (2001) in Germany and HCM (2000) in the U.S. (Table 23). Until now there is no uniform values related to pedestrian LOS in China.

As suggested in Section 4.3.1, the value of each level can be higher than that in Germany, and waiting time at E level shouldn't exceed 60s, since it is widely agreed that if pedestrian waiting time exceeds 60s, the likelihood of pedestrian non-compliance will be very high (cf. Section 2.2.2.2). The recommended values of each LOS are also listed in Table 23.

Table 23: LOS for pedestrians at signalised intersections

LOS	HCM (2000) in the U.S.	HBS(2001) in Germany	Recommended value in China
A	≤ 10	≤ 15 (20)	≤ 15
B	≤ 20	≤ 20 (25)	≤ 20
C	≤ 30	≤ 25 (30)	≤ 30
D	≤ 40	≤ 30 (35)	≤ 40
E	≤ 60	≤ 35 (40)	≤ 60
F	>60	>35 (40)	>60

The range of cycle length of 30~90 (120) seconds is recommended in RilSA (2003). The minimum cycle length suggested for use by HCM (2000) is 60 seconds, while maximum cycle which the HCM suggests is set by the local jurisdiction (such as 150 s). Considering Chinese situation, the range of cycle length in China is assumed to be 60~180 seconds.

The maximum pedestrian red time under expected level of service for pedestrians can be calculated according to Eq.16 and the final results are shown in Figure 68.

$$r_{\max} = \sqrt{2C \cdot t_{w-LOS}} \tag{16}$$

where,

r_{max}: Maximum red time under expected level of service(LOS) for pedestrians (s)

$t_{w\text{-}LOS}$: maximum pedestrian waiting time of each level of service (LOS) for pedestrians (s)

C: cycle length (s)

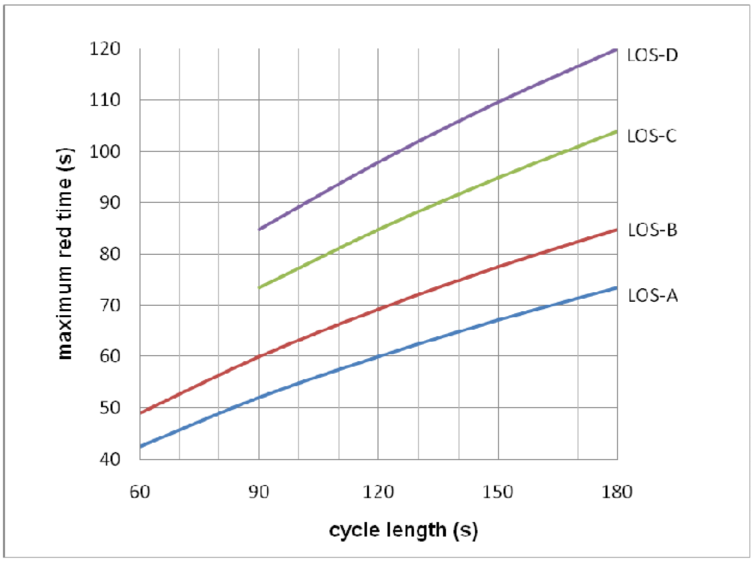


Figure 68: Maximum red time under different LOS for China

5.3.3.2 Minimum pedestrian green time

According to the MUTCD (2003), the WALK interval (namely pedestrian green time) contains pedestrian start-up time and time required for the platoon to pass a point, which is determined by number of waiting pedestrians and width of crossings (cf. Eq. 17 and Eq. 18). The MUTCD (2003) recommends at least 4~7 seconds for WALK interval.

$$t_{WALK} = 3.2 + 0.81\frac{N_{ped}}{W} \text{ (W>3.0m)} \tag{17}$$

$$t_{WALK} = 3.2 + 0.27N_{ped} \text{ (W≤3.0m)} \tag{18}$$

where,

t_{WALK}: duration of WALK interval (s)
N_{ped}: number of waiting pedestrians during an interval (p)
W: crosswalk width (m)

However, as Virkler (1998) indicated, that for crossings with relatively high volumes, platoon size has a measurable effect on the expected time for the platoon to enter the intersections, so when platoons are large, the Walk interval has to increase correspondingly. Nevertheless, at some intersections especially at big intersections, relatively short WALK interval can make pedestrians feel worried when they see the DON'T WALK display a short while after their entering, therefore, it would be very desirable to provide a longer WALK interval at some locations if possible (Zegeer, 1998).

However, as regulated in RilSA (2003), the minimum green time should ensure pedestrians to cover half of the crossing distance with a speed of 1.2 -1.5 m/s.

The U.S. method of setting minimum green time is to ensure that all waiting pedestrians can enter crossings during Green, while the German method ensures pedestrians to cover half of the crossings in order to eliminate pedestrian dilemma.

Minimum pedestrian green time in China

Minimum pedestrian green time in China is recommended to contain two parts, one part is time for releasing waiting pedestrians, since pedestrian volume is normally quite high and pedestrian platoons appear quite often, and the other part is time for covering half of the crossing.

The procedure of releasing waiting pedestrians includes pedestrian start-up time and platoon release time. Based on the investigation of 133 pedestrians in Shanghai, the average start-up time is 1.96 s, so 2.0 s is used for the calculation. Previous studies in China (Ni, 2006) indicated that the average waiting area is 0.40 m^2/p, and the average distance between adjacent rows of waiting pedestrians is 0.2 m -0.5 m and the average value of 0.35 m is used here. Minimum pedestrian green time can be calculated following Eq.22 and the time part for releasing pedestrians can be obtained from Figure 69 directly.

$$g_{\min} = 2.0 + t_{\text{platoon}} + t_{0.5L} \tag{19}$$

$$t_{\text{platoon}} = \frac{(\frac{N_{ped}}{w \times 0.40} - 1) \times 0.35}{1.20} \tag{20}$$

$$t_{0.5L} = \frac{0.50 \times L}{1.20} \tag{21}$$

so,

$$g_{\min} = 0.73\frac{N_{ped}}{w} + 0.40L + 1.71 \tag{22}$$

where,

2.0 :	pedestrian start-up time (s)
$t_{platoon}$:	platoon release time (s)
$t_{0.5L}$:	green time which ensures pedestrians to cover half of the crossing(s)
N_{ped} :	number of waiting pedestrians before Green starts (p/cyc)
W :	width of crossing (m)
L :	crossing distance (m)

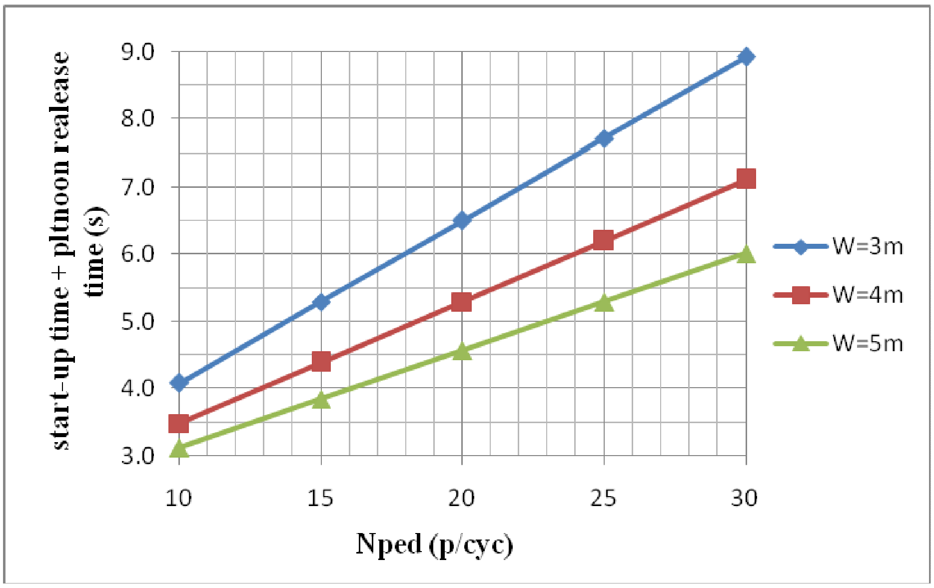


Figure 69: Time for releasing waiting pedestrians in China

5.3.3.3 Duration of pedestrian clearance time

Pedestrian clearance time is both calculated by dividing crossing distance by pedestrian clearance speed in Germany and in the U.S..

Definition of pedestrian clearance distance in the U.S. is either the distance between curb sides or distance from the curb side to the median (ITE, 1998). While in RilSA (2003), pedestrian clearance distance is also influenced by signalisation at successive crossings and conflicting traffic of next phase.

Regarding clearance speed, the MUTCD (2003) recommends 4.0 ft/s (1.22 m/s) as the normal clearance speed, and a walking speed of less than 1.2 m/s should be considered where pedestrians who walk slower than 1.2 m/s or pedestrians who use wheelchairs routinely use the crossing. However, a study by Anh Nguyen (2007) found out that when 4.0 ft/s (1.22 m/s) is used in calculating clearance interval, 60% of the intervals are deficient to some degree.

As it is recommended in RilSA (2003), pedestrians are attributed a clearance speed of 1.2 m/s, up to a maximum value of 1.5 m/s (only applied in exceptional cases). In shopping streets, recreation areas, near schools, the lower value has to be selected. In regards of protecting handicapped or elderly people, a lower value should be chosen, but it shouldn't be below 1.0 m/s, otherwise the clearance time would be experienced as much too long by other road users.

In order to avoid redundant clearance time due to using a low clearance speed, Zegeer (1998) proposed to establish passive pedestrian detection equipment, which can detect pedestrians who need more time to complete their crossing and can extend the length of the pedestrian clearance time for that particular cycle.

Duration of pedestrian clearance time in China

Clearance time calculation can follow the method in RilSA (2003). Clearance speed of 1.2~1.5 m/s is recommended. Though the clearance speeds drawn from the empirical research is quite high, the average speed of LW is 1.75 m/s (cf. Section 4.3.4), a lower value is recommended mainly out of the consideration for pedestrians with mobility impairment.

5.3.4 Pedestrian signal timing

5.3.4.1 Signalisation at successive crossings

Depending local conditions, pedestrians can offered either coordinated (including simultaneous and progressive signalisation) or separated signalisation at successive crossing on roads with refuge islands (RilSA, 2003).

(1) Under simultaneous signalisation, the same signal is shown simultaneously on the edge and on the refuge island (Figure 69), but it can't avoid pedestrians who start from Green at the first half to wait in the refuge;

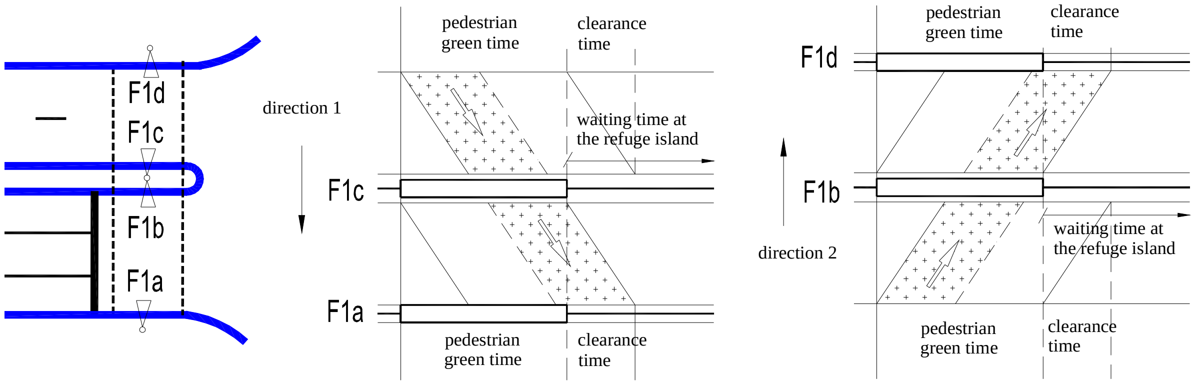


Figure 69: Simultaneous signalisation at successive crossing with one signal group (source: RilSA, 2003)

(2) Progressive signalisation employs three signal groups, different signals are displayed on the edge or on the refuge, so that all pedestrians starting from Green at the first half don't have to stop in the refuge island (Figure 70). However, the disadvantages are pedestrians may cross against signal because oncoming pedestrians are still given Green and right turning vehicles will assume Red for pedestrian and try to use their wrongly assumed priority.

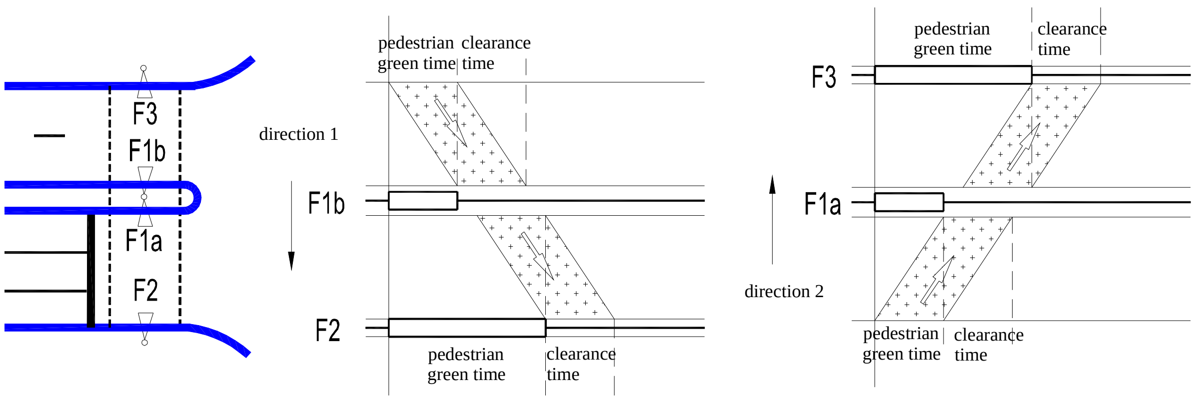


Figure 70: Progressive signalisation at successive crossing with three signal groups (source: RilSA, 2003)

(3) For separate signalisation, the two divided halves are recognised as two separate parts. For example, in Figure 71, pedestrians at the far side can have longer green time since the

intergreen time is shorter than that at the near side; in Figure 72, when protected left-turn phasing is adopted, pedestrians at both sides can have additional green time in different phases. Separate signalisation can provide pedestrians with longer green time, but the offset of green time is not helpful for signal coordination in two directions, so that more pedestrians have to wait in the refuge island.

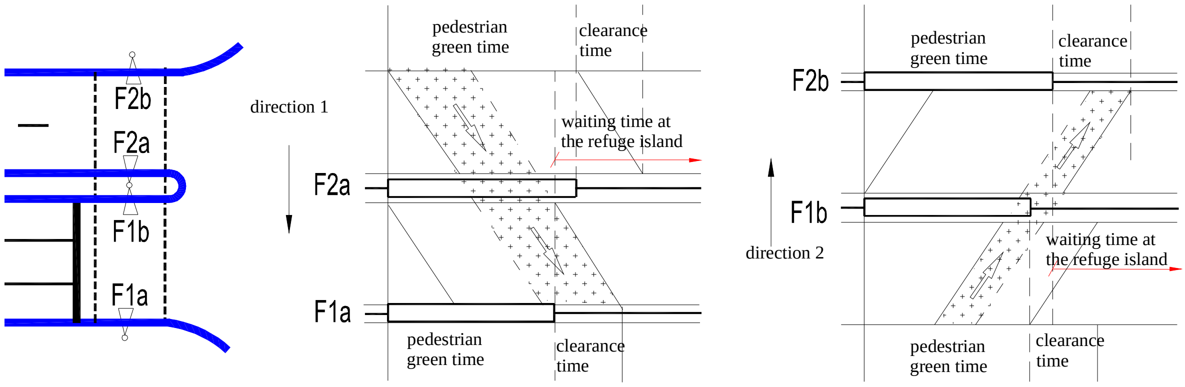


Figure 71: Separate signalisation at successive crossing with two signal groups (1)

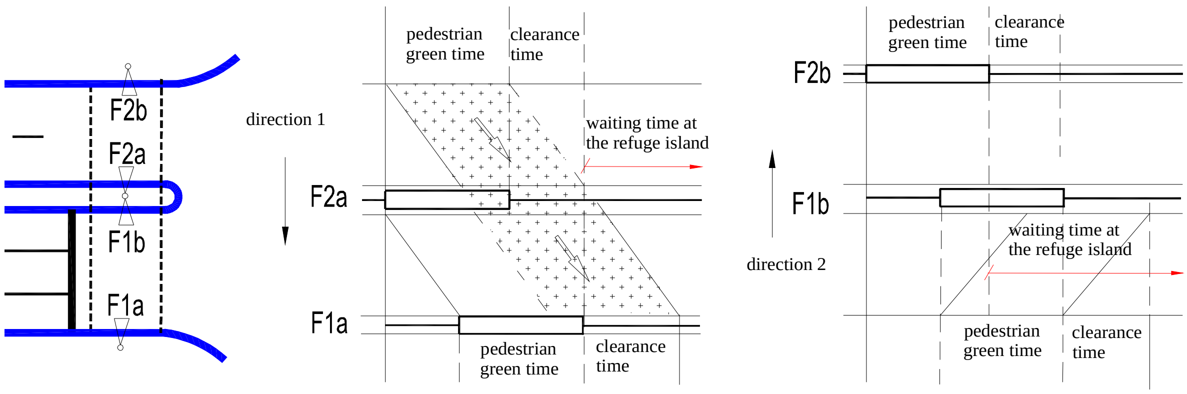


Figure 72: Separate signalisation at successive crossing with two signal groups (2)

Signalisation at successive crossings has to be considered according to possible number of pedestrians waiting at the refuge islands and width of the refuge island (RilSA, 2003). For refuge islands more than 4m wide, a separate signalisation is generally considered; while for refuge islands less than 4m wide, pedestrians should be allowed to cross the entire street in one go, i.e. without stop on the refuge island.

Application of signalisation at successive crossing in China

Table 24: Comparison of signalisations at successive crossings

	Simultaneous	Progressive	Separate
Duration of pedestrian green time (total green time of two halves)	+ +	+	+ + +
Number of pedestrians who have to wait in the refuge island	+	0	+ +
Requirement of refuge island area	+	+	+ +
Possibility of pedestrian non-compliance	+ +	+ + +	+
Feasibility in China	+ +	+	+ +
Note: +: low; + +: moderate; + + +: high; 0: zero			

Considering the characteristics of pedestrian behaviour in China: (1) pedestrians intend to cross lane by lane on multilane roads and cross half by half at crossings with refuge island when accepted gaps are available; (2) pedestrians would like to take risks to cross on Red in order to catch Green or Flashing Green of the other half when the signal states are different in two halves; (3) pedestrians try to avoid to wait in the refuge island, some recommendations of signalisation at successive crossings is given as follows:

- Progressive signalisation doesn't suit Chinese situation due to low compliance.
- Simultaneous signalisation can be widely used at intersections with permissive left-turn phasing.
- Separate signalisation is recommended to be used at intersections with partly or fully protected left-turn phasing, the area of refuge island should be sufficient to accommodate waiting pedestrians and(or) some bicycles.
- When bicycles are jointly controlled with pedestrians and the bicycle volume isn't low, separate signalisation has to be cautiously used, since the refuge island can be insufficient to accommodate many bicycles.

5.3.4.2 Signalisation of left turning movements

Basically there are three alternatives of signalisation of left-turning movements regulated in RilSA (2003) and MUTCD (2003):

- Permissive left turning movements: Circular Green signal indication is displayed, left turn is permissive to be made after yielding to pedestrians and oncoming traffic, phase transition time can also be used. It should only be applied if at least one of the two conflicting traffic streams is of low volume.
- Protected left turning movements: Left turn movements are permissive to be made when a left or right Green arrow signal indication is displayed. It must be aspired for reasons of traffic safety in the following conditions (RilSA, 2003):
  - the faster opposing traffic,
  - the more rapidly left-turning traffic flow is led,
  - the heavier left-turning traffic or a conflicting traffic flow to be crossed,
  - the more restricted the visibility of permitted traffic streams and
  - the more attentions of left-turning drivers are demanded due to the increasing number of possible conflicts (multi-lane opposing traffic, jointly right-turning vehicles, and parallel released pedestrian and cycle traffic).
  - If being allocated two or more exclusive lanes on an approach, left-turning vehicles have to be protected by signalisation.
- Temporarily protected left turning movements: Left turning movements arise by means of lagging and leading green time if the green times of opposing traffic flows are offset. In MUTCD (2003), they are also named as Permissive/Protected and Protected/Permissive.

A general impact of four left turn phasing on pedestrian safety is compared in Table 25.

Table 25: Comparison of four alternatives of left-turn phasing

Themes of left-turn phasing	Possible conflicts between GW and vehicles	Cycle length	Pedestrian non-compliance
Permissive	+ +	+	+
Protected	0	+ + +	+ + +
Permissive/Protected	+	+ +	+ +
Protected/Permissive	+	+ +	+ +
Note: +: low; + +: moderate; + + +: high; 0: no effect;			

Protection of left-turn traffic can reduce or even eliminate conflicts theoretically, but pedestrian non-compliance will go with the increase level of left-turn protection practically which will further endanger pedestrian safety.

Besides what has been mentioned in Table 25, each left-turn phasing has some other disadvantages:

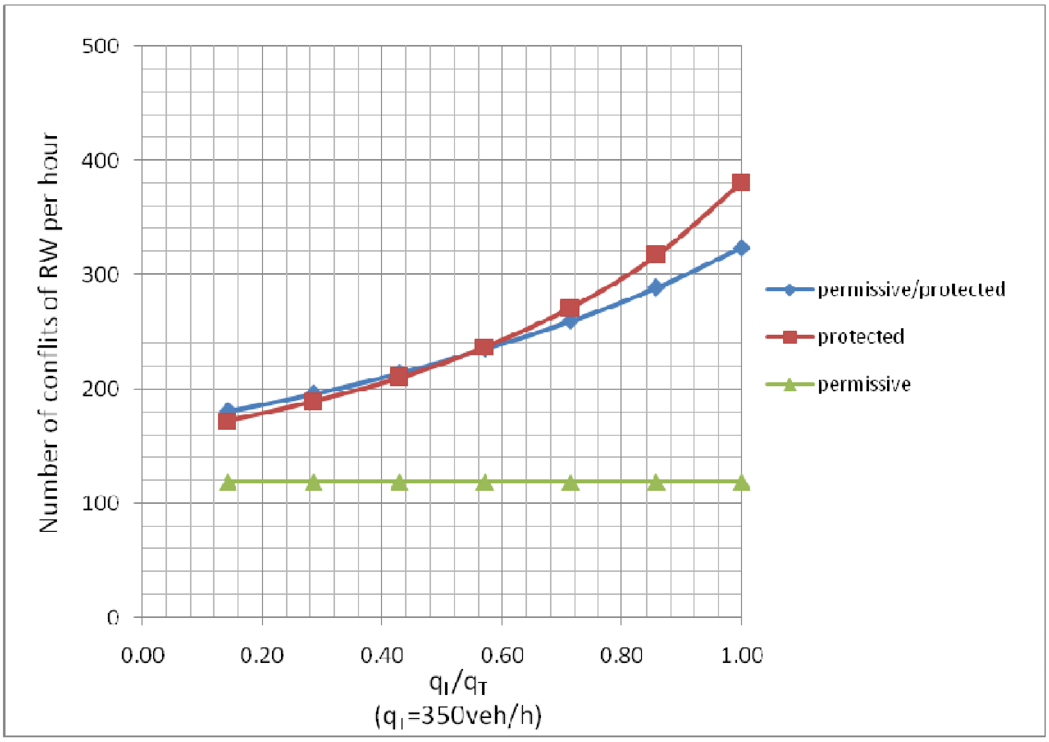
- Permissive: After searching and making use of gaps of opposing traffic, pedestrians at crossings are easily to be neglected by left-turn drivers, particularly when pedestrian volume is small. Risky situation also exists if no oncoming vehicles are present, especially at the very beginning of green time, left-turn drivers may look less at the crossing area since they assume pedestrians will not be crossing so soon (Lord, 1996).
- Protected: With the increase of pedestrian non-compliance, conflicts between left-turn vehicles and pedestrians crossing on Red will increase, and the consequence will be serious, because protected left-turn drivers have confidence on their priority and normally have high speeds, pedestrians crossing on Red are not expected.
- Permissive/Protected: Pedestrians may attempt to cross the street during the protected left-turn phase, because they see parallel through traffic is still being released.
- Protected/Permissive: Pedestrian may not pay attention to left-turn traffic because they think left-turn vehicles have been completely released during pedestrian Red time.

Application of signalisation of right-turning movements in China

A case study is taken at an intersection in Shanghai employing Chinese pedestrian behaviour models (cf. Eq.5 and Eq.10) in order to evaluate the impacts of different left-turn phasing on pedestrian safety, following measures of effectiveness (MOEs) are selected:

- number of RW+EW
- number of conflicts of RW
- average delay of GW

Model calculation details can be found in Appendix D. The final results are shown in Figure 73 and Figure 74.



q_L/q_T is a ratio, where q_L is the left turning volume, q_T is the through volume

Figure 73: Numbers of conflicts of RW under three left-turn phasing

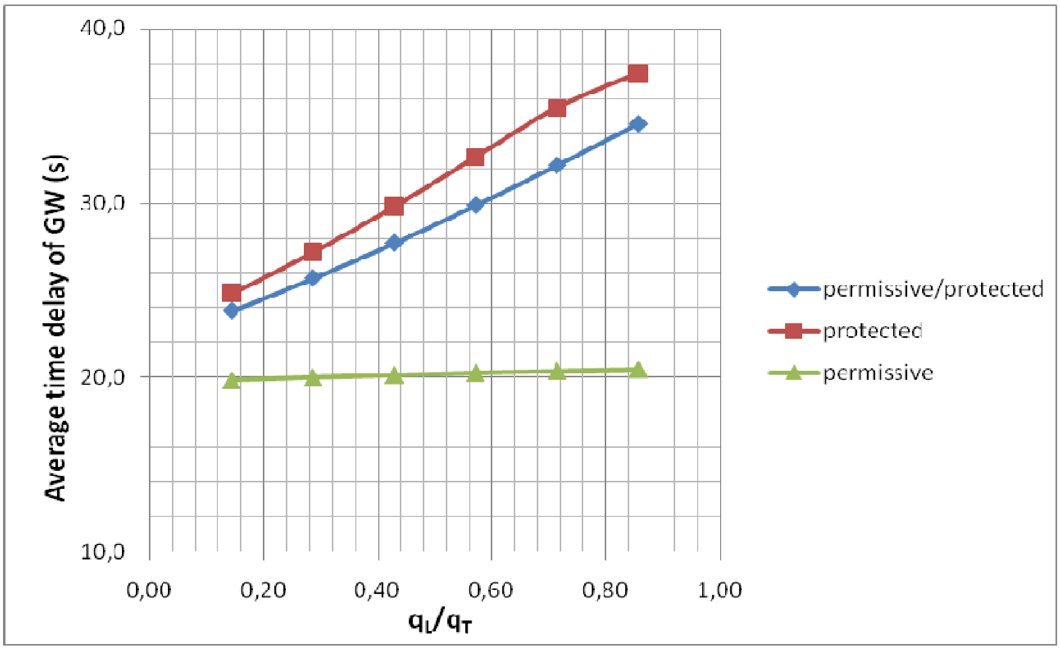


Figure 74: Average delay of GW under three left-turn phasing

The results show that:

- When left-turn volume is low (qL/qT < 0.6), permissive/protected and protected left-turn phasing results in similar conflicts of RW, when the ration of qL/qT excesses 0.6, with the increase of left-turn volume, number of conflicts of RW increases faster under protected left-turn phasing than permissive/protected phasing.

- Protected left-turn phasing always leads to the highest time delay of GW due to long cycle length and long addition red time for pedestrians.
- Total number of conflicts of both GW and RW increases significantly with the increase of pedestrian volume, while the proportion of RW and average delay of GW nearly keep the same.

In general, shorter cycle length and longer pedestrian green time encourages better signal compliance and provides better service to pedestrians, therefore permissive left-turn phasing is the best solution regarding pedestrian safety when either left turning volume or pedestrian volume is low.

However, a trade off between less non-compliance and more interactions with left-turn vehicles should be considered under the permissive left-turn phasing. A leading pedestrian interval (LPI) is strongly recommended by many researchers. LPI provides pedestrians with exclusive use of the crossing for a few seconds at the beginning of the pedestrian phase while all conflicting vehicle movements have a red light, which help to increase pedestrian visibility and alert motorists to the presence of pedestrians (Harkey, 2004). Some Application reported that 3 seconds-LPI decreased conflicts between pedestrians and vehicles, increase drivers' propensity to yield pedestrians with only slight additional delay (Van Houten, 2000). The interval is mainly determined by distance between stop line and conflict point at crossings, approach speed etc.

Besides LPI, auxiliary signs and signals can be used to alert both left turning vehicles and pedestrians. For example, flashing yellow signal used in Germany (Figure 75), in street signs warning left turning vehicles to yield to pedestrians in the U.S. (Figure 65) or marks of "Look to the left/right" on the road next to the curb side in U.K. (Figure 66)

(a) Flashing yellow signal for left turning vehicles (Darmstadt, 2009)

(b) Flashing yellow signal for right turning vehicles (Darmstadt, 2009)

Figure 75: Flashing yellow signal in Germany

When permissive left-turn phasing can't be used due to moderate or high traffic volume or some other safety reasons, control strategies with shorter cycle length is better for the sake of pedestrian safety and comfort. Normally permissive/protected left-turn phasing should be considered prior to protected left-turn phasing if only pedestrian safety is considered.

5.3.4.3 Signalisation of right turning movements

On the approaches without triangular islands

As regulated in RilSA (2003), right-turners normally do not require any signalisation by directional signals. Signal control directional signals should be considered in cases of heavy lateral traffic flows (pedestrians, bicycles, buses etc).

If directional signals are not used (permissive right turning movements), an auxiliary signal (yellow flashing light) may warn against possible conflicts with parallel priority pedestrians and cyclists if the right-turners do not clearly recognise the obligation to wait. The yellow flashing light has to be activated even during the pedestrian and cyclist clearance time.

A leading pedestrian interval (LPI) of 1~2 s is also recommended in order to ensure pedestrians to enter the crossing before right turning vehicles arrive. Meanwhile, enough space must be provided by shifting back crossings (but no more than 5~6 m), so that right turning vehicles can have a better view of pedestrians and have space to yield to them.

At intersections featuring right-turning lanes, the signal program sometimes provides additional green times for right-turning vehicles (leading or lagging green time). The beginning and end of the additional green time must be determined by intergreen time calculation to conflicting traffic flows released previously and afterwards.

On the approaches with triangular islands

According to RilSA (2003), if right turners are routed on a carriageway, they can be controlled without signalisation, and are led as waiting obligation vehicles to the crossing roads (zebra crossings and "minor and major road signs").

If road signs and markings of the carriageway are insufficient to ensure traffic safety for pedestrians and cyclists crossing the carriageway, the signalisation with the sequence Dark – Yellow – Red – Dark for vehicles at the crossing may be used. This signalisation can be controlled independently from the other parts of the intersection (for example, also traffic-actuated by requests of pedestrians).

The separated signalisation with a three-lens signal head is required for right-turning movements if:

- there are two right-turning lanes,
- visibility is impeded, or
- pedestrian and cycle traffic flow is too heavy.

Regarding the geometry design of triangular islands, Harkey and Zegeer (2004) proposed an improved design of triangular islands in order to make drivers show down and provide them with great visibilities of pedestrians, see Figure 76. Actually, the triangular island design in the right side is similarly regulated in the German guideline RAS-K-1 (1988).

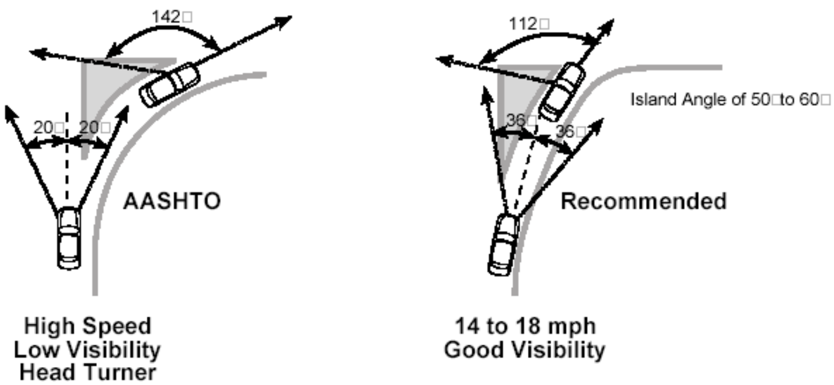


Figure 76: Comparison of two triangular island design (source: Harkey and Zegeer, 2004)

Right turn on Red (RTOR) policy

In the entire EU, right turn on Red (RTOR) is illegal, unless it is permitted by signals or signs. For instance, according to StVO in Germany, right turn on red is only permitted when a Green arrow plate (a green arrow on the dark background) is present. While in most states of the U.S.(except New York City) and Canada (except Montreal), the RTOR policy is adopted, drivers are required to have a complete stop and yield to approaching traffic before turning on red legally. In China, RTOR is permitted without interfering with other traffic.

RTOR instituted in the U.S. in 1970s was primarily to reduce fuel consumption following the energy crisis of 1973 and other potential benefits include reducing vehicle delays and emissions (Retting, 2002). However, safety problems arose and a negative effect on pedestrian safety was reported. For example, pedestrian collisions increased from 1.47 to 2.28 per year at signalised intersections following the adoption of RTOR (Preusser et al, 1981). Dussault (1993) found out an increase of pedestrian accidents by 44.2% with right turning vehicles in 8 states. Some possible reasons are listed as follows:

- Drivers focus on looking to his left for a gap while neglecting crossing pedestrians (Preusser et al, 1981).
- Many drivers fail to stop at the marked stop line and block the pedestrian crossing while waiting to turn right on red. This can impede pedestrian movement and cause some individuals to walk outside of designated crossings (Retting, 2002).
- Pedestrians have to yield to right-turning vehicles and may not able to finish crossing before conflicting vehicles start.
- Pedestrians feel uncomfortable and unsafe when they cross on Green at signalised intersections due to frequent interactions. For example, approximately 50% of respondents in a survey complained that turning vehicles do not respect pedestrians who attempt to cross during Green (Sisiopiku and Akin, 2002). The negative feelings lead pedestrian non-trust in designated crossings and signals, therefore more non-compliance is induced.
- The advantages of LPI may not be fully transferable to crossing if RTOR is applied (Saran, 2008).

Therefore, RilSA (2003) regulated that a precondition for applying the green arrow policy is a sufficient visibility on all released traffic streams, and it must not be used if the traffic signal system mostly serves traffic safety on the roads to school.

“Prohibiting RTOR” and “part-time RTOR prohibition during the busiest time” is recommended in the U.S. nowadays. Retting (2002) recommended that restricting RTOR at all times is limited to intersections where design features or other factors may increase the danger of allowing motorists to turn right on red. These include limited sight distance, unusual geometry and high traffic speeds on the intersecting street.

Regarding part-time PROT prohibition, two approaches of "restricting RTOR during specified hours" and "restricting RTOR when pedestrians are present" by providing signs is compared by Retting (2002). It was found that traffic signs prohibiting RTOR during specified hours were very effective at increasing driver compliance with stop lines, reducing the number of drivers turning right on red without stopping and reducing the number of pedestrians yielding the right of way to turning vehicles. The specified hours, for example, can be time periods with high pedestrian activities or time periods with more pedestrian accidents (e.g. 6.am~8.pm).

At intersections with low pedestrian volume, "restricting RTOR when pedestrians are present" can be realised with the help of pedestrian activation of a "No turn on red LED" sign for turning vehicles (FHWA, 2008), pedestrians can be detected by pedestrian push button or other active detections.

Application of signalisation of right-turning movements in China

- Permissive right turn phasing, together with LPI of 1~2 seconds is recommended when either right turning volume or pedestrian volume is low; when the volume is moderate or high, a leading/lagging phasing with LPI can be deployed. But in any case, the location of crossings must provide enough space for right-turning vehicles to stop for pedestrians.
- If volume of right turning traffic is high and bicycle traffic can be properly channalised, triangular islands can be considered. The design of triangular islands must ensure high visibility of pedestrians and vehicles, meanwhile, speed limitation facilities, warning signs etc. are required to reduce speed of turning vehicles.
- Considering the negative effect of RTOR, it should be prohibited all the time in the following conditions:
  - poor visibility due to geometry problems,
  - protected left turn phasing is adopted, and
  - activity of children and handicapped pedestrians exists frequently.
- Part-time prohibition of RTOR can be adopted, for instance:
  - RTOR are prohibited at intersections with high volume of pedestrians and bicycles during busy periods (e.g. 6:00~20:00).
  - When right turning volume is high and pedestrian volume is low, "restricting RTOR when pedestrians are present" can be used with the help of pedestrian activation in the future.

5.3.4.4 Exclusive pedestrian phase

Exclusive pedestrian phase, which is also called pedestrian scramble in the U.S., stops all vehicular traffic and allows pedestrians to cross at intersections in every direction at the same time, pedestrians can even cross diagonally if diagonal crossings are provided. It was first used in Kansas City and Vancouver, British Columbia, Canada in the late 1940s, and has since then been adopted in many other cities and countries, for example, in Japan until now there are more than 300 intersections with exclusive pedestrian phase (Wiki, 2009).

The U.S. national research (Zegeer, 2001) summarised that "using exclusive pedestrian intervals that stop traffic in all directions has been shown to reduce pedestrian crashes by 50 percent in some locations (i.e., downtown locations with heavy pedestrian volumes and low vehicle speeds and volumes)".

Several positive results appeared after exclusive pedestrian phase is adopted. For example, the total number of vehicle/pedestrian conflicts decreased from 7.0% to 1.1% after exclusive pedestrian phase being installed at three intersections in San Francisco (SFMTA and TSC, 2008), furthermore, among over 150 respondents, 69.5% said they felt safer with the pedestrian scramble phase in use. A strong majority favoured the phasing change, with 72% saying they liked it "very much." Meanwhile, the pedestrian scramble brought a major reduction in vehicle delays caused by conflicts between turning vehicles and pedestrians.

However, some disadvantages have to be paid attention due to the negative effect on pedestrian behaviour, for example:

- Exclusive pedestrian phase will inevitably increase the cycle length, which heighten the potential for pedestrians to cross against the signal (Andree, 2007).
- Pedestrians may desire to cross on Red when parallel traffic is released.
- Diagonal crossing requires longer clearance time. If pedestrians start to cross during clearance time and they have to take high risks of being trapped in the middle of the intersection.

Besides, the exclusive pedestrian phase takes away from available green time for vehicle movement. If the intersection is operating close to capacity and a scramble phase is introduced, significant congestion will likely occur, especially if pedestrian volume is low or moderate, additional delay of vehicles will arise (FHWA, 2008).

Application of exclusive pedestrian phase in China

Exclusive pedestrian phase is applied at several downtown intersections in Shanghai. For example, at one intersection located at a shopping area, pedestrian volume reaches 3000 p/h during peak hours, exclusive pedestrian phase and diagonal crossing is adopted. Traffic wardens are also employed at the intersection. It has been well operating, the capacity and safety of the intersection can both be ensured. Based on the successful practice, some experience can be concluded as follows:

- Exclusive pedestrian phase is suitable to be applied at intersections with high percentage of turning vehicles and high volume of pedestrians (more than 2000 p/h), such as in commercial areas, shopping areas etc.
- As pointed out by Garder (1989), the exclusive pedestrian phase can be an efficient safety measure as long as the percentage of pedestrians crossing on red is low, therefore, educational efforts are required and traffic wardens patrol at intersections with exclusive pedestrian phase is necessary.

5.3.4.5 Pedestrian push button

Pedestrian crossing requests can be sent to certain traffic control devices by pushing the button, signal timing will be changed to accommodate pedestrian crossing time. Pedestrian push button (different forms of push button can be seen in Figure 77) is normally established at locations where actuated signals do not automatically allocate sufficient pedestrian crossing time during all phases unless a pedestrian is present (MTC, 2009). If the pedestrian push button can be properly used, it can minimize delay to vehicular traffic when pedestrians are not present and ensure pedestrian crossing time when pedestrians are present, meanwhile, additional audio facilities can also be activated if necessary, which can benefit the visually impaired pedestrians.

in Germany in UK in the U.S. in China

Figure 77: Examples of pedestrian push buttons in different countries (photos from internet)

However, previous studies suggested low utility of push buttons which leads more signal violation, for example, only about half of all pedestrians used the push button (Zegeer et al., 1985) and in London was only 27% (Carsten et al., 1998). Similar problems exist in China, according to an interview in Hangzhou in 2006, only 8 pedestrians in 20 knew how to use the push button and were willing to comply the signal, while the other 12 pedestrians didn't know how to use it nor didn't want to use it because pushing the button took efforts or sometimes they were not easily accessible.

There are some possible reasons for low utility of push buttons, for example:

- Pedestrians may not be aware that pressing the button is necessary to obtain the Walk signal, because many signals do not have a push button and automatically allocate a Walk interval on every cycle (Hughes et al., 2001).
- Even when pedestrians are aware of the requirement, the delay between the time that the push button is pressed and the Walk signal appears can be long enough that some pedestrians think that the system doesn't work.
- Improper locations of push buttons hamper the utility as well.
  - Pedestrians are confused by push buttons established at the same pole if the arrow indication is missing, they don't know which button for which crossing direction;
  - Visually impaired pedestrians may not realize that the push button exists or may not be able to find it (Bentzen and Tabor, 1998).
  - Pedestrians with severe mobility impairments may be unable to push the button.

Application of pedestrian push button in China

Most pedestrian push buttons are used at mid-block crossings in China, it is more difficult to establish pedestrian activation of signals at intersections, because the traffic actuated control technology in China is still low. The following issues have to be considered if pedestrian push button will be installed at intersections in the future.

- Pedestrian push button is suitable to be established at intersections with low or significant fluctuating pedestrian volumes.
- System feedback after the button being pushed is necessary to make pedestrians trust the facility is working and will provide green time for them soon and the response time shouldn't be too long.
- Informational signs or traffic wardens nearby are necessary to explain methods of using the push button.

- Pedestrian push button should be located with high visibility and accessibility.

5.3.4.6 Automatic pedestrian detection

Automated pedestrian detection (Figure 78), on the one hand, pedestrian Green is provided only when pedestrians are present, on the other hand, it can not only detect the presence and departure of pedestrians at curb side or refuge island, but also pedestrians in the crossing. The automated detection can avoid low utility which is a big problem for pedestrian push button.

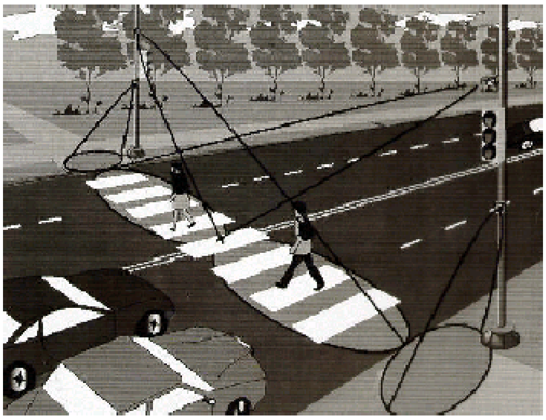


Figure 78: An automated pedestrian detection system (source: FHWA, 1997)

A number of different automated pedestrian detection including infrared, microwave and video image processing are reported to be used (e.g. Zegeer et al., 1994; Ekman, 1992; King, 1994).

The UK Department of Transport (1993) reported the system operated at Puffin (Pedestrian User-Friendly Intelligent) crossings :

- Pedestrian presence is sensed either by use of a pressure-sensitive mat or by an infrared detector mounted above the crossing location. If the pedestrian departs the crossing zone, prior to the appearance of the Walk signal, the call will be cancelled.
- An additional sensor is employed to detect the continued presence of pedestrians in the crossing, thereby allowing the signal phase to be extended for those requiring additional time to cross.

It has been proved that the use of automatic detection can lead positive changes in pedestrian behaviour. For example, studies carried in Los Angeles (Hughes, 2000) claimed that the use of the microwave detector together with the push button reduced pedestrian signal violation by 81%.

However, the detection accuracy such as false alarms or missed calls have to be paid attention. Beckwith and Hunter-Zaworski (1998) tested the microwave and infrared detectors in Portland. The results showed that microwave detectors performed better than infrared detectors in terms of fewer false calls (1% vs. 4%). Microwave detectors were more likely to miss calls (7% vs. 1.5%).

Additionally, special consideration should be taken into account when the local intersection is located in a coordinated signal system, because when pedestrian push buttons or automated detections are activated, the local intersection is disconnected from the system for one cycle to serve pedestrians, the practice will degrade the effectiveness of the system if activation is frequent (ITE, 1998). It has been recommended by ITE (1998) that pedestrian actuated signal control is only used when pedestrian volume is light and when WALK time limit vehicle movement timing.

Application of automated pedestrian detection in China

It is not suitable to use automated pedestrian detection at signalised intersections in China, at least from the short term point of view.

- The biggest problem is high pedestrian volume in China. If pedestrians arrive during each cycle, it is unnecessary to use automated detection to provide pedestrians with crossing time.
- The extended green time is supposed to protect pedestrians who can't finish crossing before Red, however, it may encourage more pedestrians to violate the signal, especially during clearance time. The high cost of device installation and maintenance and risks of inducing more pedestrian non-compliance must be considered.

5.3.5 Summary of measures of signal control

Generally speaking, selection of signalisation of turning movements is more depend on the local situations, especially the traffic volume of pedestrians and turning vehicles. Figure 79 provides a simple way to select signal control strategies based on a rough estimation of traffic volume.

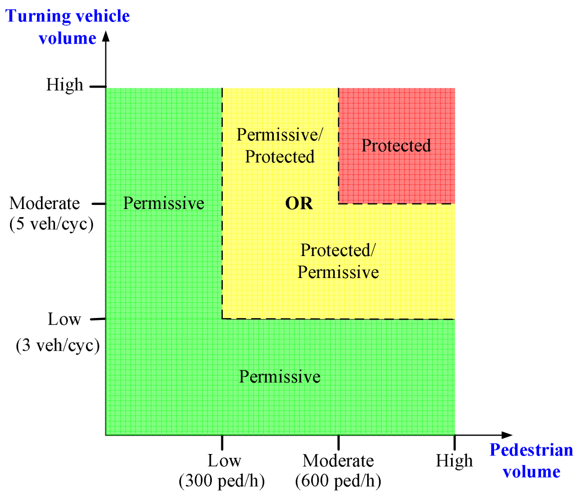


Figure 79: Recommended signalisation of turning traffic

The requirements on parameters of pedestrian signal program including maximum red time, minimum green time and adequate clearance time (cf. Section 5.3.3) should be regulated in the national guideline and satisfied in practice.

Measures regarding pedestrian signal indications (cf. Section 5.3.2) and pedestrian signal timing (cf. Section 5.3.4) are evaluated from aspects of effects on improving pedestrian safety if applied properly, influence on capacity of motorised traffic and cost, and the short-term or long-term feasibility of each measure in China is concluded, as listed in Table 26.

Table 26: Summary of measures of signal control

No.	measures	Improve pedestrian safety (when acceptance is high)	Influence on capacity of motorised traffic	Cost	Feasibility short term (long term)
1	Display of pedestrian clearance time	+ +	0	+	+ +
2	Countdown signals during clearance time	+ + (+)	0	+ +	+ +
3	Countdown signals indicating remaining red time	- / 0 (+)	0	+ +	+ +
4	Permissive turn phasing + LPI	+ +	0	0	+ +
5	Permissive turn phasing +flashing yellow / signs / pavement marking	+ (+)	0	+	+ +
6	Partly or fully protected turn phasing	+ (+)	+	0	+ +
7	Restriction of “right turn on red (RTOR) ”	+ (+)	-	+	+ +
8	Exclusive pedestrian phase with diagonal crossing	+ (+)	- / 0	+	+ +
9	Time-dependent signal program	+ +	+ +	0	+ +
10	Vehicle actuation	+ +	+ + +	+ +	+ (+)
11	Pedestrian push button with system feedback +signs	+ (+)	- / 0	+ +	+ (+)
12	Automated pedestrian detection	+ (+)	-	+ + +	+ (+)

Note: +: positive low; + +: positive moderate; + + +: positive high; 0: no effect; -: negative effect

5.4 Measures of traffic education

Providing education and training is a key strategy in increasing pedestrian and motorist awareness and reducing risk behaviour. Since changing behaviour can be a long and arduous task, traffic education should aim at long-term results. To implement the strategy, an integrated, multidisciplinary approach that links hard policies (e.g., changes in infrastructure), soft policies (e.g., public relations campaigns) and addresses both pedestrians and drivers has the greatest chance of success (Harkey and Zegeer , 2004).

Firstly, knowledge of meanings of signals and signs, regulation of right-of-way, correct crossing behaviour, use of traffic facilities (e.g. pedestrian push button) etc. has to be included in the public traffic education.

Brinks (1990) in Netherland found that there were severe deficiencies with regard to the knowledge of priority rules, particularly when right of way is not indicated by signs or road marks. Also the knowledge of rules governing complex manoeuvre (such as turning left at an intersection) is inadequate.

A good example of knowledge provided by educational material on pedestrian crossing at signalised crossings in Australia (Mainroad, 2009) includes following contents with simply and easily understandable interpretations: (1)Know your pedestrian traffic signals; (2)Remember turning vehicles must give way to pedestrians; (3)Take the time to cross safely.

Based on the recent studies on pedestrian safety, important elements of traffic education program among bicyclists, pedestrians, and motorist are proposed by FHWA (2006):

- Teach important bicycling and walking skills to youngsters: work with school administrators and teachers to identify target ages for key educational messages.
- Teach important bicycling and walking skills to adults: work with college and high school administrators and teachers to identify key educational messages.
- Include bike and pedestrian information in driver training: work with local driver training instructors and violators to identify key messages for delivery to new drivers, as well as those required to take remedial driving courses.
- Determine which safety messages are most important for which audiences.
- Create a process for effectively delivering those messages: work with the local media and other groups to determine the best way to reach the audiences identified above, given the resources available.

For example, The DETR (Department of the Environment, Transport and the Regions) in Netherland has continued and increased the "shock index" level of its “Kill your Speed TV” adverts, employing home video of actual child victims. These stress appropriate speeds rather than simply staying within speed limits (Hummel, 1999).

As mentioned above, education campaigns to target groups are necessary in order to give proper education to specific groups with certain behaviour patterns (e.g., motorists, elderly, school children, adults). Education for children and the elderly has been paid more attention in Australia, Germany, the U.S.,Netherland etc .

For children: School education and “Safe routes to school programs”

Victoria(Australia) is among the leaders in developing educational materials for use in schools and has published thorough-going evaluations of its programs from pre-school through to secondary school. Anthony and Wilcock (1991) found that 55% of early childhood centres used “Starting Out Safely”, a program aimed at developing safe pedestrian and restraint use behaviour for pre-schoolers. 78% of primary schools included traffic safety education in the curriculum while 88% of secondary schools using at least one of the traffic safety lessons developed by VicRoads(a subordinate authority which is the State's road and traffic authority in Victoria, Australia) and 80% using two or more (Anthony et al 1992). Study of traffic education in Victoria indicated that primary schools spent an average 86.8 hours teaching road safety, compared to an average of 57.9 hours in secondary schools (Harrison et al. 1997). The use of resources varied considerably between years and grade levels.

"Safe routes to school programs" in Australia are a package of measures aimed at reducing the risk encountered in the journeys to school through a package of integrated activities, including the promotion of the safest routes, the provision of some low-cost engineering treatments to reduce risk at hazardous locations, and education of the broad school community in the philosophy behind the route and its safe use.

For the elderly

It was pointed out by Van Wolffelaar (1988), the elderly should learn to cope adequately with the effects of aging. The main targets of traffic education of elderly traffic participants should be:

- Primarily education: Improvement of the knowledge of traffic rules and traffic skills;
- Secondary education: Improvement of the knowledge of the effects of aging, learning to cope with loss of function (compensation), and acknowledgement of the need of a good mental and physical condition.

Walk with care is a program provided throughout Victoria, Australia, which is aimed at improving the safety of elderly pedestrians. It focuses on high accident locations, the essential elements of the program include (Cairney, 1999):

- Specially trained volunteer discussion leaders conduct sessions with groups of older residents throughout a municipality to give information about safe ways of using roads and collect information on problem spots.
- A survey is distributed to older persons throughout the municipality to supplement the discussions.
- Council staff determines necessary engineering works on the basis of discussion group outcomes, survey results, and crash statistics.
- Engineering works and safety messages are publicized through local newspapers, information bulletins, and municipal newsletters.

Program evaluation

Since education is a long-term measure, it is difficult to evaluate education programs by their effects on crash reductions, rather some other evaluation methods like interviews, behaviour observation can be employed. For example, Cairney (1999) proposed one method in Australia: Giving leaflets with information about correct crossing procedures to people crossing the road incorrectly, followed one week later by enforcement of pedestrian regulations at the same site, video recording of crossing behaviour, and continuing group discussions at three monthly intervals.

Application of traffic education in China

- Education of basic knowledge of traffic regulations, correct behaviour of pedestrians, cyclists and drivers etc. must be provided to the public as soon as possible. Possible approaches include TV advertisement, community study, leaflets delivery etc. As an important social activity, it requires a multidisciplinary cooperation including traffic engineers, police, educational organizations etc.
- A system of traffic education must be developed with target groups of children, adults and the elderly.
- Enhanced traffic education in schools has to be attached importance, for example, the traffic education curriculum should be added.

- Education of drivers in drive schools should add more information about consideration of pedestrians and cyclists.

5.5 Measures of traffic law enforcement

In the first place, before applying law enforcement, corresponding traffic laws have to be reviewed and modified if necessary. Considering pedestrian safety at signalised intersections, traffic laws with regard to pedestrian signals, pedestrian behaviour at signalised crossings and driver behaviour when passing crossings have to be reviewed.

Over the years, traffic laws regarding driver behaviour such as speeding, running red lights, driving after drinking alcohol, illegal parking etc is world-widely enforced, effective and socially accepted methods have been developed for measuring such behaviour (Harkey and Zegeer , 2004). Automated enforcement of traffic signals and speed limits, using photo radar and video camera systems connected to the signal control, is an increasingly common and cost-effective approach to improve driver compliance with traffic laws (NCTRP, 2004).

Regarding pedestrian safety, the enforcement at signalised intersections ought to preserve pedestrian right-of-way and force pedestrians not to violate the signal nor cross outside the designated crossings. Meanwhile, the enforcement on the part of pedestrians is generally not attached much importance to, possibly because of the reasons as follows (Cairney, 1999):

- Low monetary fines for most offends, hence perceived low importance.
- Many of the offends require a lot of police time to detect, either because they occur with very low frequency at any particular place or the presence of police deters their occurrence.
- Automated enforcement techniques can't be employed.

In fact, the easiest way of traffic enforcement on pedestrians is the presence of polices or traffic wardens. According to investigations in this study, the relative proportion of RW at one crossing with traffic wardens in Shanghai (S(2,2,0)-3) is only 1% , while the average value of the other two similar crossings (S(2,2,0)-1,S(2,2,0)-2) without polices or traffic wardens is 38%. Early studies carried out in the U.S. (Heraty, 1986 quoting Winer, 1968) also showed there was an increase by 30% in the number of legal crossings, when police officers patrolled in collision hot spots.

Location targeted for enforcement (presence of polices traffic wardens) can be determined by analysis of accident statistics and conflict studies. In some cases, public input or observations by law enforcement personnel may suggest that a location should be targeted for enforcement (NCTRP, 2004). However, it is important to check intersections that would benefit from enforcement. Care should be taken to ensure that the layout design and signal control of the intersection is appropriate, and the existing signals are operating properly as well.

In the U.S., there are particular enforcement programs called “Pedestrian sting operations” (TRB, 2009), which target motorists who violate the right-of-way of pedestrians crossing the street. Plain-clothed police officers step into marked crossings to see if drivers will yield to them. If the driver does not stop, the plain-clothed officer radios to a police officer in a car ahead, who stops and tickets the driver. This type of operation results in drivers receiving a penalty that is directly related to a pedestrian safety violation.

However, we must bear in mind is that targeted enforcement of traffic laws is a short-term, moderate-cost measure to address site specific signalised intersection safety. Though this is an effective strategy, the effectiveness has often been found to be short-lived (NCTRP, 2004). It is difficult to provide constant enforcement of traffic regulations due to funding and staffing reasons, so periodic enforcement may be necessary to sustain the effectiveness of this strategy. Furthermore, well-publicized enforcement campaigns are often effective when combined with strategically installed traffic control devices and public education programs. (Harkey and Zegeer , 2004)

Application of traffic enforcement in China

- Improve traffic laws related to pedestrians crossing at signalised intersections. For example, the meanings of pedestrian signals such as Flashing Green and countdown signals have to be clearly explained and corresponding pedestrian behaviour has to be regulated as well.
- More traffic wardens can be employed to patrol at the intersections, not only correct false behaviour of pedestrians, but also warn turning vehicles to yield to pedestrians.
- Enhanced enforcement like more frequent ticketing of traffic violations or higher fines can be considered.
- Programs targeting speeding vehicles in residential areas with frequent activities of children and elderly are also necessary.

5.6 Conclusions

Traffic engineering measures aiming to establish pedestrian-friendly facilities have been analysed, the feasibility of applying measures in China has been drawn out basically from three aspects:

- the efficiency to improve pedestrian safety under high acceptance level,
- the influence on vehicular capacity, and
- cost.

In Table 27, functions of each feasible measure in China to fulfill relevant objectives are listed.

Actually, in order to have high level of pedestrian acceptance of measures mentioned above, traffic education and traffic law enforcement should be attached more importance.

Requirements of pedestrian crossing facilities and application approaches of feasible measures including traffic education, traffic law enforcement and traffic engineering will be summarised in the form of a “draft of guidelines” in Chapter 6.

Table 27: Feasible traffic engineering measures in China and their functions

Measures	**Objective 1** Reduce expected conflicts	**Objective 2** Eliminate undesired conflicts		
		Objectiev2-1 High pedestrian compliance		**Objectiev2-2** High motorist compliance
		Cross at designated crossings	Obey signals	Yield to pedestrians
Refuge island	×	×	×	×
Curb extension		×		×
Reduced curb radii		×		×
Raised crossing		×		×
Guard rails		×	×	
Transit stops at far side	×			
Integrated design of transit stops and crossings	×	×		
Signs (pavement marking) to prompt pedestrians	×	×	×	
Signs to prompt motorists	×			×
Pedestrian red time doesn't exceed maximum red time			×	
Pedestrian green time longer than minimum green time	×			
Adequate clearance time	×			
Display of pedestrian clearance time	×		×	
Countdown signals during clearance time			×	
Countdown signals indicating remaining red time			×	
Permissive turn phasing + LPI/ flashing yellow / signs / pavement marking	×		×	×
Partly or fully protected turn phasing	×			
Restriction of "right turn on red (RTOR) "	×			
Exclusive pedestrian phase with diagonal crossing	×	×		
Time-dependent signal program			×	
Vehicle actuation			×	
Pedestrian push button with system feedback		×	×	
Automated pedestrian detection		×	×	

6. Guidelines for Pedestrian Safety at Urban Signalised Intersections (Draft)

6.1 Introduction

As a complement to the existing national codes of traffic planning and design in China, the drafted "guidelines for pedestrian at urban signalised intersections" aim to provide specific instructions on pedestrian crossing traffic at signalised intersections at urban inner areas in order to improve the service for pedestrians. It follows the traffic laws in China.

The guidelines treat pedestrian traffic as the integrated component of road users at signalised intersections, requirements of other road users including motorised vehicles, bicycles, public transport are also taken into consideration.

Guidelines are drafted on the basis of analysing pedestrian safety problems in China (cf. Chapter 4) and evaluation of feasible measures in Chapter 5, they are provided from the aspects of traffic planning, management, design, operation, education and enforcement, in which the intersection layout design and signal control is more focused.

6.2 General remarks

6.2.1 Pedestrian characteristics at signalised intersections

There are several characteristics of pedestrians crossing at signalised intersections, which include:

- **Vulnerability:** Pedestrian accidents happen frequently at signalised intersections and the accident severity is the highest among all road users. Compared with motorised traffic, pedestrians are easily to lose their right-of -way.
- **Negative attitudes towards regulations:** Pedestrian non-compliance at signalised intersections including crossing outside the crossing and signal violation, which is quite common and the rare law enforcement on pedestrians deteriorate the situation.
- **Flexibility:** Pedestrian movement patterns including crossing decisions, attention, visual searching, speeds and routes vary from different pedestrian types under different situations.
- **Conformity:** Pedestrians prefer to cross in a group and have same behaviour with others, if one pedestrian cross against the signal, it is quite possible some one else follows.
- **Waiting-time sensibility:** Pedestrian crossing on Red is mostly to save time, the likelihood of pedestrian non-compliance increases with the increase of pedestrian waiting time.
- **Gap-based violation:** Pedestrians would like to use accepted gaps during Red, they prefer crossing lane by lane at multilane roads or half by half at crossings with refuge islands to waiting until Green.

6.2.2 Basic requirements

Traffic systems need to provide safe and convenient service for all road users, including pedestrians. At sites with high level of pedestrian importance, more consideration regarding pedestrians should be given. Pedestrian importance is related to the frequency of pedestrian activity and main types of pedestrian especially children, the elderly and the disabled. Sites with high level of pedestrian importance include commercial areas (e.g. shopping centres, general retailers, entertainment facilities etc.), residential areas, schools, bead houses, hospitals etc.

Pedestrian-friendly facilities are required to ensure pedestrian safety and convenience through the procedure of traffic planning and management, traffic design and operation, together with enhanced public traffic education and well-publicized traffic enforcement campaigns.

Pedestrian-friendly facilities should satisfy the following requirements:

- reduced vehicle volume and speed
- increased visibility for vehicles and pedestrians
- ample space for waiting and walking
- short crossing distance
- signs and signals with high visibility and clear meanings
- short waiting time
- required minimum green time
- sufficient clearance time
- reduced conflicts between pedestrians and vehicles
- successive crossing without stops
- consideration for the disabled pedestrians and children.

Pedestrian average waiting time is used as the criterion to evaluate pedestrian level of service (LOS) at signalised intersections, shown in Table 6-1.

Table 6-1: Pedestrian Level of Service

Level of service(LOS)	pedestrian average waiting time
A	≤ 15s
B	≤ 20s
C	≤ 30s
D	≤ 40s
E	≤ 60s
F	>60s
Note: pedestrian average waiting time $t_w = \frac{(C-g)^2}{2C}$ C: cycle length (s); g: effective pedestrian green time, displayed green time plus 2~4 s.	

6.3 Guidelines on traffic education

Traffic education aims to provide road users with knowledge on traffic regulations and relevant safe behaviour, educate road users to have correct attitudes as traffic participants, so that traffic awareness can be increased and risk behaviour can be reduced. It is a long-term strategy to improve traffic safety and requires a multidisciplinary cooperation including traffic engineers, traffic police, educational organizations and media.

Regarding pedestrian crossing traffic at signalised intersections, knowledge including meanings of signals and signs, regulation of right-of-way, correct crossing behaviour and methods to use pedestrian crossing facilities (e.g. pedestrian push button) must be included in the public education. Besides general public education, targeted education for different groups of children, adults and the elderly is required with special consideration on characteristics of each group.

(1) Traffic education at schools (from kindergarten to secondary school) for children and adolescent is quite basic, a school traffic education system including traffic curriculum and practical exercises is urgent to be developed.

(2) More information on the consideration of pedestrians and cyclists should be added at drive schools.

6.4 Guidelines on traffic law enforcement

Traffic law enforcement at certain sites aims to reduce non-compliance of road users through legal approaches.

At first, relevant traffic laws have to be reviewed and to be modified if necessary. Location targeted for enforcement can be determined by analysis of crash statistics and conflict studies. It is important to check intersections that would benefit from enforcement, care should be taken to ensure that the layout design and signal control of the intersection is appropriate, and the existing signals are operating properly as well.

Regarding pedestrian crossing traffic at signalised intersections, the easiest way is to have polices or traffic wardens patrol at the intersections and warn pedestrians and drivers who violate regulations, e.g. pedestrians cross against signals or outside of the crossing and drivers don't yield to pedestrians.

Other approaches like monetary fines, especially for drivers can be applied after communication with relevant departments.

6.5 Guidelines on traffic planning and management

Traffic planning should take pedestrian safety and convenience into account and, measures of traffic management can be used to reduce vehicle volume and speeds, especially for areas with frequent pedestrian activities, such as schools, senior centres, residential areas, shopping areas etc. Safety-oriented traffic planning has to be started in the field of land use planning.

Accident data is the fundamental issue for safety management and it is essential for finding out safety problems and identifying hazardous locations, therefore, a transparent system of accident data collection and analysis is urgently required.

6.6 Guidelines on layout design

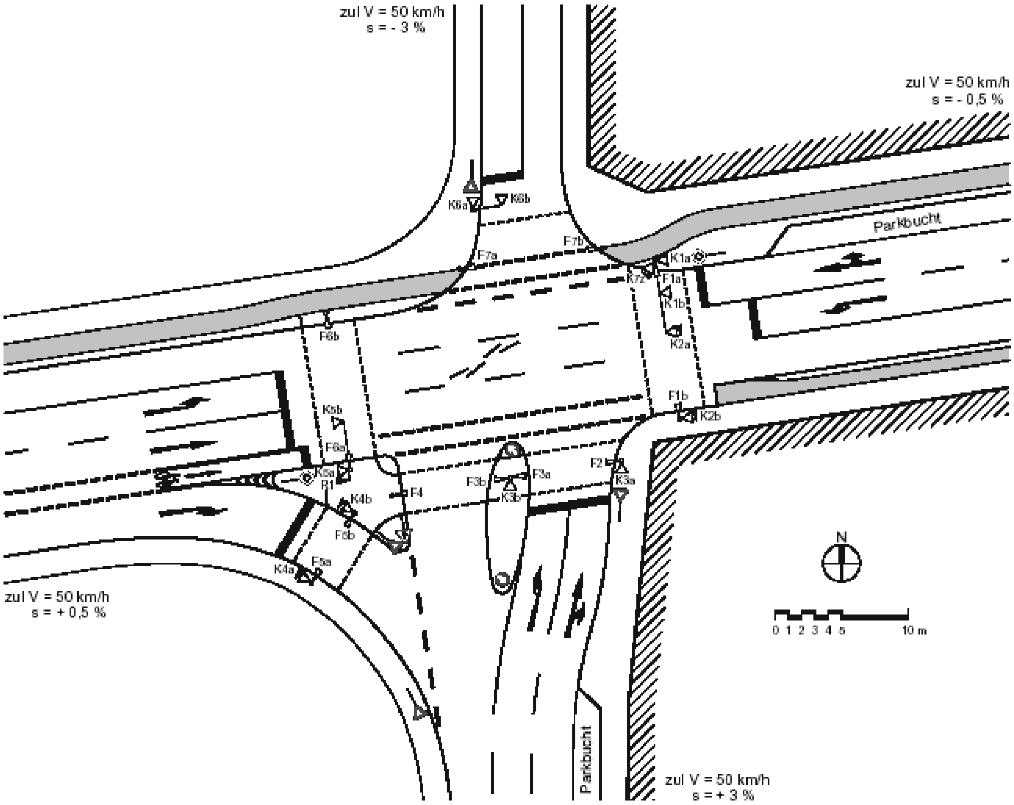


Figure 6-1: Example of layout design related to crossings (source: RilSA, 2003)

6.6.1 Pedestrian crossings

It is recommended to have different markings of crossings with signal control and without. Parallel dash lines can be used at signalised crossings, while zebra crossings can be used without signal control, pedestrians have priority when crossing at zebra crossings.

Pedestrian crossings should be established at each leg of the intersections unless certain restrictions of safety problems or other reasons, because pedestrians tend to cross directly from the origin to the destination, long detour should be avoided. If crossing at one leg is prohibited, guard rails must be deployed around the street corners.

Crossings should be located as near as the edge of the parallel road as possible in order to have better inter-visibility between pedestrians and motorists. If right turning traffic is released together with the parallel pedestrians, the crossing must be set back for 5.0 m to 6.0 m from the edge of the carriage way in order to accommodate a right turning passenger car. The minimum distance between pedestrian crossing and stop line is 1.0 m.

A standard width of pedestrian crossings is 4.0 m, the minimum width is 3.0 m. When bicycles are jointly controlled with pedestrians, a separate crossing for bicycles should be established and the width should be no less than the width of bicycle lanes. When the crossing is wider than 8.0 m, another signal head is required.

Waiting area at the curb sides and islands (refuge islands in the middle and triangular islands) should be sufficient, generally the design density is 2~3 ped/m^2 and 1 bicycle/1.5 m^2. If waiting area isn't enough, cycle length or pedestrian red time have to be shortened.

Illumination, drainage and antiskid of crossing have to be considered as well.

In order to prevent pedestrians from crossing at undesired sites, guard rails should be deployed along sidewalks or refuge islands under following conditions:

- main streets with high vehicle volume and high speed
- major pedestrian generators(e.g. school, supermarket etc.) are located nearby intersections
- bus stops located on sidewalks nearby intersections;
- crossing at one or more legs of intersections are prohibited;
- refuge islands of staggered crossings.

6.6.2 Refuge islands

Refuge islands should be established at wide streets where the crossing distance covering motorised lanes exceeds 15.0 m. The minimum width of refuge islands is 1.8m, the area should be sufficient to accommodate pedestrians and cyclists under certain signalisation at successive crossing (see 6.9.3), too small refuge islands have to be expanded, for example, by using staggered crossings or even at the expense of reducing carriageway width or the number of lanes.

The illuminated bollards or reflection facilities are necessary to be provided to minimize the potential of drivers running into the refuges in darkness.

6.6.3 Triangular islands

It is necessary to establish triangular islands at skewed intersections (with an entry angle smaller than 70° or larger than 108°) in order to improve visibility of motorists.

Triangular islands can also be used at perpendicular intersections with high volume of right turning vehicles. A well designed triangular island can on the one hand optimize the right-turning motorist view of pedestrians and of vehicles to his(her) left, on the other hand, reduce pedestrian crossing distance and consequently clearance time (Figure 6-1).

Zebra crossing is recommended to connect triangular islands and curb sides in order to avoid additional waiting time for pedestrians, signs waning drivers to yield to pedestrians should be erected. If more than one right turning lane exists or speed of right turning is high, signalised crossing should be established for safety sake.

6.6.4 Traffic calming facilities

Small curb radii are beneficial to reduce pedestrian crossing distance and avoid too smooth right turning movement, generally a curb radius of 10 m ~15 m is recommended.

Other traffic calming facilities including curb extension, raised crossings can be used at intersections in residential area in order to reduce vehicle speed and make it more possible for motorists to yield to pedestrians. Curb extensions should only be used where there is a parking lane and shouldn't extend more than 1.8m from the curb, the turning needs of larger vehicles, buses also need to be considered.

6.6.5 Transit bus stops

When bus stops are designed on the sidewalk, it is better to locate bus stops at the far side of intersections when passenger volume is high and make it as near to the crossing as possible, since pedestrians may cross behind the bus, visibility between pedestrians and oncoming traffic can be enhanced. Guard rails along the sidewalk are necessary so as to guide pedestrians to cross at the designated crossing.

When transit stops are designed in the middle (e.g. BRT stops), the bus stop is recommended to be integrated with crossings, shown in Figure 6-2.

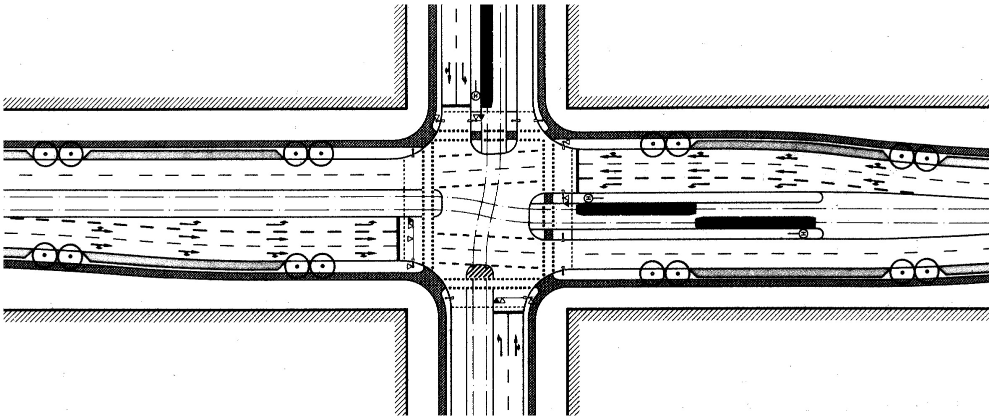


Figure 6-2: integrated design of bus stops and crossings at signalised intersections (source: RAS-K-1, 1988)

6.6.6 Signs

Signs to prompt turning drivers to yield to pedestrians are necessary to be erected at intersections with permissive turn phasing and at zebra crossings which are connected to triangular islands.

Signs mounted adjacent to or integral with pedestrian push button are required to explain purpose and use of the push button. Other signs providing pedestrians with information of meanings of pedestrian signals, warning pedestrians of turning traffic can be applied as well in order to inform pedestrians of safe behaviour.

6.7 Guidelines on pedestrian signal indication

6.7.1 Basic pedestrian signal indications

Pedestrian signal heads provide special traffic signal indications exclusively intended for controlling pedestrian traffic. These signal indications consist of the illuminated symbols of **a Green Walking Person**, **a Flashing Red Walking Person** and **a Red Standing Person**, they have following meanings individually:

(1) **A Green Walking Person (Green)** means that a pedestrian facing the signal indication is permitted to start to cross the roadway in the direction of the signal indication, possibly in conflict with turning traffic.

(2) **A Flashing Red Walking Person(Flashing Red)** indicates pedestrian clearance interval, it means that a pedestrian shall not start to cross the roadway in the direction of the signal indication, but that any pedestrian who has already started to cross on a Green Walking Person indication(Green) shall proceed out of the travelled way.

(3) **A Red Standing Person (Red)** means that a pedestrian shall not enter the roadway in the direction of the signal indication.

High visibility of signals is required, since pedestrian signal heads are mostly located at the opposite side of the street, if the street is too wide, signal heads should also be established on refuge islands.

6.7.2 Countdown pedestrian signals

A Countdown signal displaying simultaneously with Flashing Red informs pedestrians of the remaining time of clearance interval, which is beneficial to eliminate pedestrian dilemma during signal change and increase pedestrian perception of safety. Pedestrians can also adjust their speeds in order to finish crossing before Red. However, the big disadvantage is that pedestrians would be encouraged to start to cross during clearance time. Moreover, the countdown signals can't be installed in a traffic actuation system.

A countdown signal displaying simultaneously with Red provides pedestrians with remaining waiting time, which can help to prolong pedestrian accepted waiting time, but the displaying time mustn't be too long (it mustn't exceed the threshold waiting time of pedestrians, for example, 60s), otherwise it will induce more signal violation.

Countdown signals starting from the beginning of Green, or countdown signals displaying separately with Green and Flashing Red should be avoided, since pedestrians will be confused by the meanings of remaining times.

6.7.3 Auxiliary signals

One unit signal heads with yellow flashing light can be used to warn hazards, black symbols (pedestrian, bus) on yellow optical units are allowed (Figure 6-3). Yellow flashing signal with pedestrian symbol can be used to warn turning vehicles to pay attention to crossing pedestrians, especially at intersections with poor visibility, for example, the stop-line is far away from the pedestrian crossing.

The flashing light has to be activated during both pedestrian green time and clearance time. Yellow flashing signal with bus symbol can be installed to warn pedestrians of oncoming buses at transit stops located in the middle of the road.

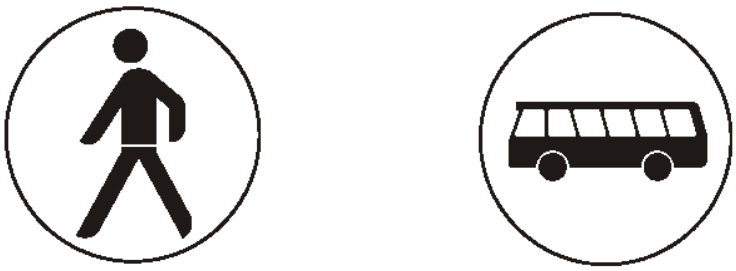


Figure 6-3: Signal heads with yellow flashing light (source: RilSA, 2003)

6.8 Guidelines on pedestrian signal program

6.8.1 Maximum pedestrian red time

When pedestrian average waiting time exceeds 60s, the likelihood of pedestrian non-compliance will be very high, therefore, pedestrian red time shouldn't exceed the maximum red time under different cycle lengths of a designed pedestrian level of service (LOS).

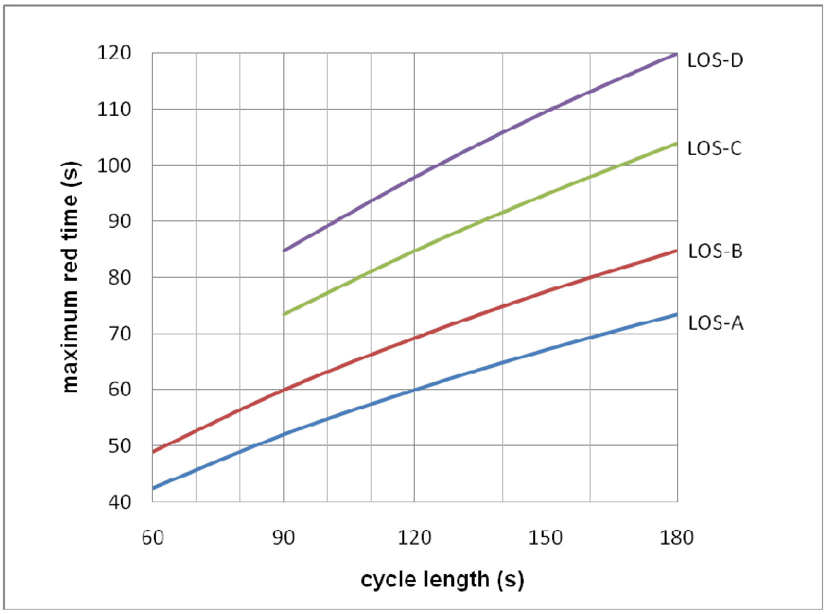


Figure 6-4: Maximum red time under different cycle times

Meanwhile, pedestrian red time is restricted by the waiting area, if waiting area can't accommodate waiting pedestrians, shorter red time have to be used.

6.8.2 Minimum pedestrian green time

Minimum pedestrian green time ensures (1) all waiting pedestrians during Red can enter crossings, assuming pedestrian start-up time is 2.0 s, and (2) minimum distance can be covered at the speed of 1.2 m/s, however, the minimum distance differs in the following conditions:

(1) At crossings without refuge islands: pedestrians can reach the centre of the crossing;

(2) At crossings with refuge islands (except crossings with separate signalisation): pedestrians can reach the centre of the second half of the crossing;

(3) At crossings with separate signalisation: pedestrians can reach the centre of each half of the crossing.

$$g_{\min} = 0.73\frac{N_{ped}}{w} + 0.40L + 1.71$$

where,

g_{min}: minimum pedestrian green time
N_{ped}: number of waiting pedestrians before Green starts (p/cyc)
w: width of crossing (m)
L: crossing distance (m)

6.8.3 Pedestrian clearance time

Pedestrian clearance time is the time needed to cover the clearance distance at a clearance speed.

Pedestrian clearance distance is calculated from the edge of the curb side until the farther edge of the conflict area. Under most circumstances, the clearance distance is the whole width of the road if there is no refuge island. At crossings with refuge islands in the middle, the clearance distance is the width of each half of the road separated by the refuge island. For diagonal crossings, the clearance distance is the maximum length of diagonal crossings.

Pedestrian clearance speed is 1.2 m/s, up to a maximum of 1.5 m/s. In shopping streets, recreation areas, near school etc.the lower value has to be selected. Where crosings have been installed to protect handicapped or elderly pedestrians, e.g. residential area, near hospital, near beadhouse etc.lower clearance speed should be chosen equally, but shouldn't fall below 1.0 m/s, otherwise, it will bring too long waiting time for other road users.

6.9 Guidelines on pedestrian signal timing

6.9.1 Pedestrians and turning vehicles

Pedestrians and vehicles should be separated by signalisation (protected turn phasing) at intersections (triangular islands) where:

(1) the visibility of pedestrians and motorists is poor due to geometry reasons (e.g. skewed intersections);

(2) both pedestrian and turning volumes are high, more than one turn lane exists;

(3) vehicle speeds are high;

(4) frequent activities of child pedestrians, the elderly and pedestrians with visual disabilities exist.

However, full signal protection of turning traffic leads to longer waiting time for all road users and pedestrian non-compliance may be induced consequently.

At intersections with good visibility of pedestrians and motorists, permissive or part-time protected turn phasing can be applied when traffic load is low or moderate. If either pedestrian volume or turning volume is low, permissive turn phasing is recommended, since waiting time of all road users can be shortened. Under other circumstances, lagging or leading turn phasing can be selected depending on relevant traffic volumes.

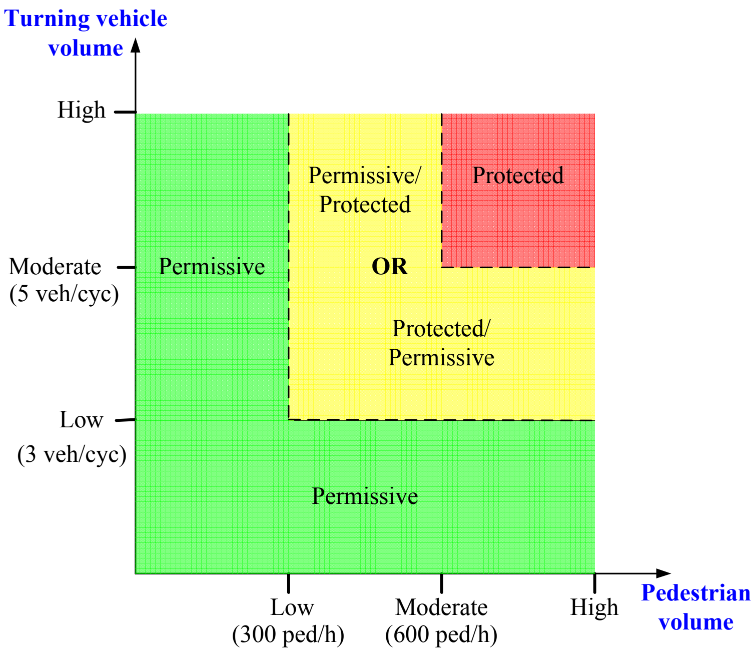


Figure 6-5: Signalisation of turning movements based on traffic volume

A leading pedestrian interval (LPI) of 1~2 s should be applied with permissive turn phasing so that pedestrian visibility can be enhanced since pedestrians can step into the crossing before turning vehicles reach. Turning vehicles can be warned of priority of pedestrians by Yellow flashing signal (see 6.7.3); meanwhile, pedestrians can also be warned of permissive turning vehicles by pavement markings of "LOOK LEFT" or "LOOK RIGHT".

With reference to "Right turning on Red" (RTOR), RTOR should be fully prohibited all the time in the following conditions:

- Poor visibility due to geometry problems(e.g. skewed intersections);
- Protected left turn phasing is adopted;
- Activity of children and handicapped pedestrians exists frequently;

Part-time prohibition of RTOR can be adopted in the two ways:

- during busy periods(e.g. 6:00~20:00);
- when pedestrians are present if pedestrian volume is always low and pedestrian detection is available .

6.9.2 Exclusive pedestrian phase

Exclusive pedestrian phase stops all vehicular traffic and allows pedestrians to cross at intersections in every direction at the same time, it can be applied at intersections with high volume of pedestrians (more than 2000p/h) and low or moderate volume of vehicles with high proportion of turning traffic. Diagonal crossing can be allowed if demand of diagonal crossing is high.

However, exclusive pedestrian phase will increase cycle length and lead to additional waiting time of all road users. If vehicular traffic is already over-saturated, the exclusive pedestrian phase isn't recommended. When diagonal crossing is allowed, pedestrian waiting time for diagonal crossing shouldn't exceed the total waiting time under signalisation without exclusive pedestrian phase.

6.9.3 Signalisation at successive crossings

Signalisation at successive crossing mainly includes simultaneous signalisation, progressive signalisation and separate signalisation. The former two are coordinated signalisation, majority or all of pedestrians starting at Green of the first part can cross the whole crossing successively in two directions, while the separate signalisation can provide pedestrians with longer green time, but the offset green time can only ensure coordination in one direction.

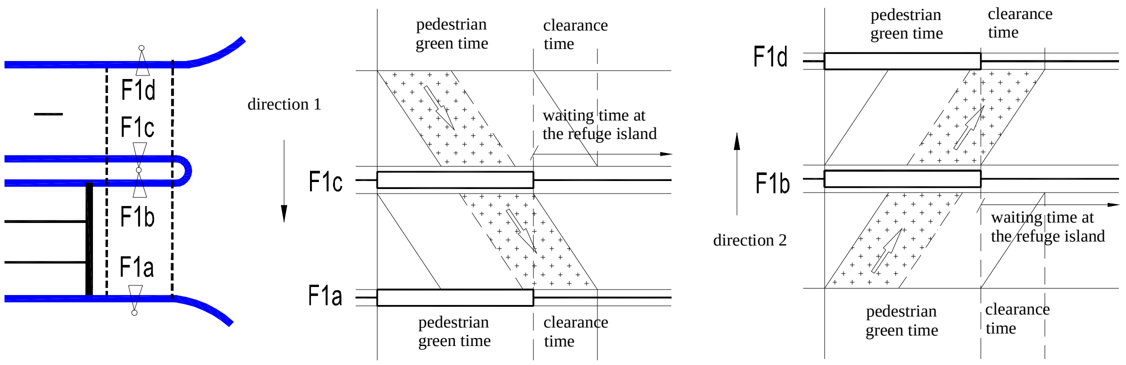


Figure 6-6: Simultaneous signalisation at successive crossing with one signal group

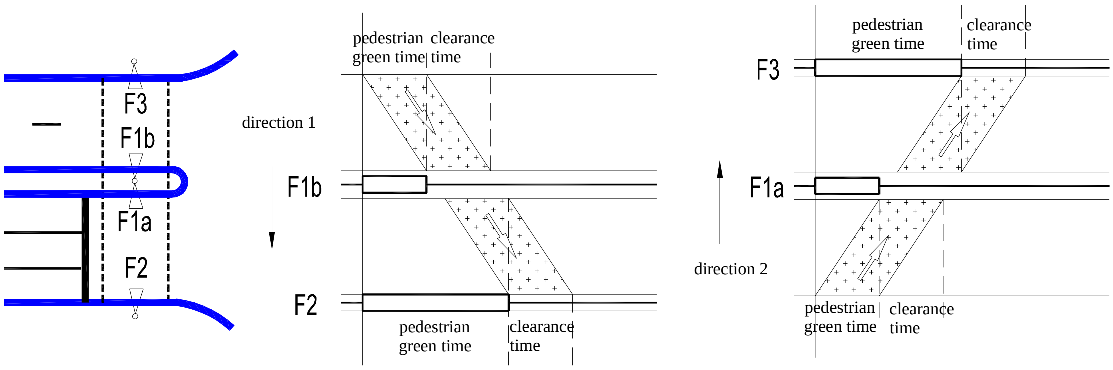


Figure 6-7: Progressive signalisation at successive crossing with three signal groups

(1) Simultaneous signalisation can be widely used at intersections with permissive left- turn phasing.

(2) Progressive signalisation can be used if the refuge island is small and pedestrian volume is low.

(3) Separate signalisation can be used at intersections with partly or fully protected left-turn phasing, and the area of refuge island should be sufficient to accommodate waiting pedestrians and(or) some bicycles.

(4) When bicycles are jointly controlled with pedestrians, separate signalisation has to be cautiously used, because bicycles require much more areas.

6.9.4 Pedestrian actuation

In a traffic adaptive control systems, pedestrian requests can be fulfilled in two different ways:

(1) Parallel routed pedestrians and vehicle stream are generally released simultaneously, even if green time has been requested by either pedestrians or vehicles only. This may lead to longer waiting times for all road users due to long pedestrian clearance time.

(2) A pedestrian green time is only switched if requested by pedestrians. It can be assigned separately or jointly with parallel vehicle traffic. If pedestrians arrive shortly before or during vehicle green without a parallel pedestrian green time, the request has to be stored until suitable in the phase sequence, which results in long waiting time for pedestrians.

The first approach is generally used, while the second approach can be used at intersections with low pedestrian volumes or where pedestrian volumes fluctuate significantly, especially if the intersection is located at a coordinated control system.

Pedestrian detectors include pedestrian push button and other automated detections (e.g. infrared, microwave and video image processing). A system feedback after pedestrian pushing the button is necessary and push button response time shouldn't be too long.

Pedestrian push button should be located with high visibility and accessibility, and can be easily activated. At crossings under simultaneous or separate signalisation, push buttons also have to be installed at refuge islands because pedestrians are expected to wait at refuge islands as well.

6.10 Consideration for the disabled

A smooth, obstruction-free path should be available at all times. Ramps at curbs and raised refuge islands should be provided for pedestrians using wheelchairs. When necessary, raised guide strips at pedestrian crossings are also recommended to provide assistance to the people with impaired vision.

Accessible pedestrian signals can provide information in non-visual format (such as audible tones, verbal messages, vibrating surfaces) for pedestrians who have visual disabilities. If pedestrian clearance time is sufficient only to cross from the curb to the refuge island, the accessible pedestrian signals should be provided in the refuge islands as well.

6.11 Checklist of layout design and traffic control

The checklist is used for estimating the pedestrian safety and level of service at signalised intersection, it contains following most important points:

(1) Good visibility between pedestrians and vehicles, if not, certain measures like setting up triangular islands, adopting protected turn phasing etc. are taken;

(2) The curb radius is reasonable, less than 15m at intersections without triangular island; 20~25m at intersections with triangular island.

(3) Refuge island exists if the total width of motorised lanes exceeds 15m;

(4) Signal heads are installed also on the refuge island;

(5) Waiting area is enough for pedestrians(and bicycles) at the curb side and at the refuge island;

(6) Pedestrian green time is longer than minimum green time;

(7) Pedestrian clearance time is sufficient;

(8) Pedestrian level of service (LOS) which based on average pedestrian waiting time reaches the designed level;

(9) Reasonable turn phasing (permissive, protected, lagging and leading protected) is adopted under the current conditions of land use, traffic volume, number of turning lanes and vehicle speeds etc.;

(10) The crossing is shifted and signs warning turning vehicles to yield to pedestrians are installed, if permissive right-turning is adopted.

(11) A pedestrian leading interval of 1~2s is used if permissive turning is adopted.

(12) Pedestrian exclusive phase only used when pedestrian volume is high, while the vehicle traffic is unsaturated;

(13) Signs indicating use of pedestrian push button exists when push button is installed.

(14) Guard rails are installed along sidewalks where pedestrians are easily cross outside the crossings such as near bus stop;

(15) Guard rails are installed at refuge island of staggered crossing;

(16) Bus stop is located at far side when passenger volume is high.

(17) Required facilities for the disabled if the crossing is located at the site with frequent activities of the disabled.

7. Conclusions and outlook

7.1 Conclusions

As the weakest traffic participants, pedestrians are easily involved in serious traffic accidents in urban areas, and the majority of pedestrian accidents happened at signalised intersections. In China, pedestrian fatalities account for nearly 30% of all traffic deaths in average year, and they are about 135 times higher than those in Germany under the same motorisation level. Therefore, a research aiming at improving pedestrian safety at signalised intersections has been carried out and several conclusions have been drawn out based on theoretical and empirical studies as follows.

Evaluation method of pedestrian safety at signalised intersections

Traffic situation analysis (TSA) has been proved to be an effective method to evaluate pedestrian safety at intersections:

- on the one hand, it provides a comprehensive view of traffic situations since complete information of "traffic situations" (e.g. behaviour, traffic conditions, intersection geometry and layout, signal control) are required to obtain;
- on the other hand, TSA distinguishes interactions (interactions obeying traffic rules and encounters) when pedestrians comply with signals from conflicts due to non-compliance by at least one of the traffic participants. Different levels of interaction are distinguished according to the non-compliant behaviour and the executor of a manoeuvre. Moreover, manoeuvres of pedestrians are easily to be observed, so that the accuracy to evaluate interactions and conflicts can be high.

Influencing factors on pedestrian safety at signalised intersections

Influencing factors on pedestrian safety have been sorted into seven groups, which are background factors, human factors, intersection geometry and layout factors, traffic factors, signal control factors, behaviour factors and traffic education and law enforcement factors. The most critical factor on pedestrian safety can be attributed to improper behaviour of road uses mainly including pedestrian non-compliance (account for 20% to all pedestrian fatalities in China), pedestrian improper "visual search behaviour" and drivers fail to yield to pedestrians, which is influenced by other factors directly or indirectly.

The influencing factors play roles of different importance levels under different situations and the relationship among factors are complicated, some of them are consistent with each other, while some of them have goal-conflicts, for example, the decreased pedestrian crossing difficulty through setting up refuge islands or reduce road width can induce more pedestrian non-compliance.

Pedestrian safety problems at signalised intersections in China

Firstly, mixed traffic creates a more complicated situation to be handled by pedestrians at signalised intersections in China.

Secondly, low traffic discipline of road users is the major problem endangers pedestrian safety. On one hand, pedestrian non-compliance is quite common, most of them consider their non-compliance blameless and would like to accept gaps during Red and prepare to have conflicts with vehicles when crossing on Red; on the other hand, vehicle drivers and cyclists seldom yield to pedestrians who cross on Green.

Thirdly, non-friendly pedestrian crossing facilities at signalised intersections such as poor visibility between pedestrians and vehicles, too smooth turning movements, too long clearance distance, too long waiting time and insufficient crossing time etc. deteriorate pedestrian safety and easily induce improper behaviour of pedestrians and drivers which results in a vicious circle threatening pedestrian safety.

Last but not the least, lack of traffic education for decades and deficiencies of traffic laws and enforcement increases the difficulty to improve pedestrian safety in a short time.

Three-E-measures to improve pedestrian safety at signalised intersections in China

Basically, pedestrian traffic should be taken into account in the procedure of traffic planning, design and operation and pedestrian- friendly facilities are required at locations with high volume of pedestrians, especially high activities of the elderly, children and the disabled pedestrians. What's more, traffic education programs aimed at the public and targeted groups (school traffic education must be attached more importance), improved traffic laws, efficient measures of law enforcement are required as well to ensure a high acceptance and compliance of traffic laws and facilities.

Guidelines for pedestrian safety at signalised intersections has been drafted based on consideration of pedestrian safety problems and three-E-measures with efficiency and feasibility in China.

Limitation of the research

- "Before-and –after" method is the basic way to evaluate effectiveness of safety measures in practice, and normally three or more years of collision records are required. However, it is not so easy to have trials of measures in China and it would take long time, therefore, only theoretical calculation based on behaviour models drawn from empirical studies has been carried out in the research.
- In the research, motorised vehicles are considered to be the most critical threat to pedestrian safety, while conflicts between pedestrians and bicycles are not sufficiently considered .

7.2 Outlook

Regarding future study on pedestrian traffic at signalised intersections, the following studies can be considered.

- An integrated intersection design consideration of all road users, including motorised vehicles, bicycles and pedestrians.
- Accommodate pedestrian traffic in a signal system in order to have the optimum service for all road users.
- Introduce ITS technology on pedestrian safety, for example, a navigation system provides optimum route for pedestrians with consideration of waiting time at signalised intersections; include pedestrians in the on-going Vehicle-To-Infrastructure-Integration (V2I) work, i.e., adding pedestrian sensing and treatment and changing the focus to "Vehicle-Infrastructure-Traveller-Integration".
- Develop other approaches to improve pedestrian safety, such as the vehicle technology of "Pedestrian safety through vehicle design".

List of Abbreviations

General	Unit	Meaning
GW	(-)	Green Walkers
LW	(-)	Late Walkers
RW	(-)	Risk Walkers
EW	(-)	Early Walkers
TCT	(-)	Traffic Conflict Technique
TSA	(-)	Traffic Situation Analysis
PET	(-)	post encroachment time

Parameters	Unit	Meaning
C	s	cycle length
d_{GW}	s	total delay of GW
g_{min}	s	Minimum pedestrian green time
h	s	average headway of conflicting traffic flow during pedestrian red time
L	m	pedestrian crossing distance
l	m	pedestrian clearance distance
N_{CT}	p	number of pedestrians arriving during clearance time (p)
N_R	p	number of pedestrians arriving during Red time (p)
$N_{GW/RW/EW\text{-}(R+CT)}$	p	number of GW, RW, EW who arrive during Red and clearance time during observation period (p)
N_{LW}	p	number of LW during observation period (p)
N_{ped}	p/cyc	number of waiting pedestrians before Green starts in a cycle
$N_{GW/LW/RW/EW\text{-}int/conf}$	p	number of GW, LW, RW, EW involved in interactions/conflicts (p)
$n_{int/conf\text{-}GW/LW/RW/EW}$	p*veh	total number of interactions/conflicts with GW, LW, RW, EW involved
n_i	(-)	number of lanes related to stream qi
$p_{abs\text{-}GW/LW/RW/EW}$	%	absolute proportions of GW, LW, RW, EW
$p_{rel\text{-}GW/RW/EW}$	%	relative proportions of GW, RW, EW
$p_{rel\text{-}LW}$	%	relative proportions of LW
p_{RW+EW}	%	relative proportion of RW and EW
$p_{int/conf\text{-}GW/LW/RW/EW}$	%	proportions of GW, LW, RW, EW with interactions
q_i	veh/h	traffic volume of the ith stream
Q_{veh}	veh/h	volume of relevant conflicting vehicles
$R_{GW/LW/RW/EW}$	(-)	Risk factor of GW, LW, RW, EW
$\overline{t}_{level1}$	s	average interaction time for GW
r	s	effective pedestrian red time
r_{max}	s	maximum red time under expected LOS for pedestrians
$t_{w\text{-}LOS}$	s	maximum pedestrian waiting time of each LOS for pedestrians
t_w	s	average pedestrian waiting time
t_{WALK}	s	duration of WALK interval (U.S. definition)
W_1	s	waiting time for Green
W_2	s	pedestrian discharging time
W_3	s	total interaction time
w	m	width of crossing
Δt_s	s	post encroachment time

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ABBAS,M.H. (2007)
Correlational Analysis of Drivers Personality traits and Styles in a Distributed Simulated Driving Environment
Dissertation, Linköping University, Sweden

AJZEN, I. (1991)
"The Theory of Planned Behavior".
Organizational Behaviour And Human Decision Process 50, pp. 179-211

ALPHARAIL (2009)
Retrieved from: http://www.alpharail.co.uk/guardrail.aspx

ANDREE, R. (2007)
Handbuch für Verkehrssicherheit und Verkehrstechnik.
Hessische Straßen-und Verkehrsverwaltung

ANDROSCH.W (1975)
Untersuchung zur Signalfolge an Knotenpunkt
Darmstadt

ANGENENDT.W, ERKE.H, HOFFMANN.G, MARBURGER.E.A ,MOLT.W, ZIMMERMANN.G (1987)
Situationsbezogene Sicherheitkriterien im Straßenverkehr. Heft 18, Berichte der Bundesanstalt für Straßenwesen, Bereich Unfallforschung.
Bundesanstalt für Straßenwesen

ANTHONY, S. ,WILCOCK, C. (1991).
Traffic Safety Education in Victoria. Volume1 - Early Childhood Centres 1990.
VicRoads Report GR 91-12.

ARHIN, S. A. , NOEL, E. C. (2007)
"Impact of Countdown Pedestrian Signals on Pedestrian Behavior and Perception of Intersection Safety in the District of Columbia".
In: "Proc. IEEE Intelligent Transportation Systems Conference ITSC 2007", pp. 337-342

ARIANE, T., AUBERLET, J.M, ROLAND, B. (2007)
"Perceptive and cognitive process in the pedestrian decision-making: How Do Pedestrians Cross at Intersection ?"
In: "ICTCT Extra Workshop, Beijing Proceedings".

ASABA,M., SAITO,T. (1998)
"A Study On Pedestrian Signal Phase Indication System".
In: "Road Transport Information and Control, 1998. 9th International Conference on (Conf. Publ. No. 454)", pp.182-185

AUSTIN K, P. , MARTIN, B. (1996)
"Improving pedestrian priority in UTC systems"
In: Traffic management and road safety. Proceedings of Seminar H held at the PTRC European Transport Forum, Brunel University, England.

BAASS, K. G. (1989)
"Review of European and North American Practice of Pedestrian Signal Timing".
Roads and Transportation Association of Canada 5, pp. 55-74

BACHMANN, C. (2008)
"Methoden der Verkehrssicherheitsforschung im Straßenwesen - Anwendungen und Erkenntnisse"
Universität Hannover

BANERJEE, I., SHLADOVER, S.E., MISENER, J.A., CHAN, C.Y., RAGLAND,D.R. (2004)
"Impact of Pedestrian Presence on Movement of Left-Turning Vehicles: Method, Preliminary Results & Possible Use in Intersection Decision Support" .
In: " TRB 85th Annual Meeting Compendium of Papers CD-ROM"

BARKER, D. J., WONG, Y. W. , YUE, W. I. (1991)
Pedestrian violations at signalised crossing facilities.
Aust. Road Research(21), pp.22-28.

BECKWITH, D.M., HUNTER-ZAWORSKI, K.M. (1998)
Passive Pedestrian Detection at Unsignalized Crossings.
In: " TRB 77th Annual Meeting Compendium of Papers CD-ROM"

BENNETT,S., FELTON,A., AKCELIK, R. (2001)
"Pedestrian movement characteristics at signalised intersections".
In: "23rd Conference of Australian Institutes of Transport Research"

BENTZEN, B.L. , TABOR, L. (1998).
Accessible Pedestrian Signals
Retrieved from: http://www.walkinginfo.org/aps/

BERGER, W.G. (1975)
Urban pedestrian accident countermeasures experimental evaluation.
Prepared for National Traffic Safety Administration and Federal Highway Administration

BERNHOFT, I.M., CARSTENSEN ,G. (2008)
"Preferences and behaviour of pedestrians and cyclists by age and gender".
Transportation Research Part F 11(2), pp. 83-95

BIEHL, B.M., OLDER,S.J. , GRIEP, D.J. (1970)
Pedestrian Safety: A Report by an OECD Research Group
Organization for Economic Co-operation and Development
Paris

BOLTZE,M., FRIEDRICH, B., JENTSCH,H., KITTLER,W., LENHOFF,N., REUSSWIG,A. (2006)
Analyse und Bewertung neuer Forschungserkenntnisse zur Lichtsignalsteuerung, Berichte der Bundesanstalt für Straßenwesen, vol V149.
Bundesanstalt für Straßenwesen MARTIN, A (2006)

BREWER, M., FITZPATRICK,K., WHITACRE, J. LORD,D. (2006)
"Exploration of Pedestrian Gap Acceptance Behaviour at Selected Locations".
Transportation research record (1982), pp.132-140

BRINKS, J. (1990)
"Traffic Related Knowledge, Attitudes and Risk Perception in Dutch Secondary School Children; Consequences for Traffic Education" .
In: "Proceedings of Road Safety and Traffic Environment in Europe." VTI report 364, p. 31-43. Gothenburg, Sweden.

Bundesminister für Verkehr, Bau und Stadtentwicklung (BMVBS),(2009)
Retrieved from: http://www.bmvbs.de/dokumente/,302.7253/Publikationen/dokument.htm

CAIRNEY, P. (1999)
Pedestrian Safety in Australia
U.S. Federal Highway Administration

CAMERON, M.H. (1982)
"A Method of Measuring Exposure to Pedestrian Accident Risk".
Accident Analysis and Prevention 14(5), pp. 397-405

CARSTEN ,O.M.J, SHERBOURNE, D.J. , ROTHENGATTER, J. A. (1998).
Intelligent traffic signals for pedestrians: evaluation of trials in three countries. Transportation Research Part C6, pp. 213- 229

CELIKKAN, Y., HOFFMANN, A., SCHLABBACH, K. (2008)
Restrotanzeige für Fußgänger
Straßenverkehrstechnik 52, pp. 20-25

China Daily (2009)
Retrieved from: http://www.chinadaily.com.cn/china/2009-06/05/content_8253533.htm

CRABTREE, M. R. (2002)
"Smart pedestrian counter system (SPECS)".
In: RTIC 2002 : road transport inforamtion and control (London, 19-21 March 2002)" pp. 100-104

CRADDOCK, B.S. (1992)
"The fundamentals of pedestrian accidents at signalised junctions" . In: "Road Traffic Monitoring, 1992 (IEE Conf. Pub. 355)"

CARTER,D.L., HUNTER,W.M., CHARLES V., ZEGEER,C.V., STEWART,J.R. , HUANG, H.F. (2006)
Pedestrian and Bicyclist Intersection Safety Indices
U.S. Department of Transportation
FHWA-HRT-06-125

CATCHPOLE, J. (1996)
Further Development of the Puffin Pedestrian Crossing.
Victoria, Australia.

CHU,X.H., GUTTENPLAN, M., MALTES, M.R.(2004)
"Why People Cross Where They Do: The Role of Street Environment".
Transportation Research Record (1878), pp. 3-10

DAFF ,R., CRAMPHORN, B., WILSON, C. J. , NEYLAN, J. (1991)
"Pedestrian behaviour near signalised crossings (Sydney)"
In: Proceedings 16th ARRB Conference, part 4

DANNICK, L. I. (1973)
Influence of an anonymous stranger on a routine decision to act or not to act: An experiment in conformity.
Sociological Quarterly(14), pp.127-134

DAS, S., MANSKI, C.F, Manuszak , M. D (2005)
Walk or Wait? An Empirical Analysis of Street Crossing Decisions
Joural of Applied Econometrics, 20(4), pp. 529-548

DAVIES, D.G. (1999)
Research, Development, and Implementation of Pedestrian Safety Facilities in the United Kingdom.
U.S. Federal Highway Administration
FHWA-RD-99-089

DE LA SABLIÈRE, P. (1988)
La sécurité des piétons. Circuler(24), pp.9-24.

DIAZ, E. M. (2002)
"Theory of planned behavior and pedestrians' intentions to violate traffic regulations".
Transportation Research Part F 5, pp. 169-175

DONG, L.H.(2004)
"Pedestrian Non-compliance and Traffic Accidents".
In: "Proceeding of 2004 international symposium of traffic safety"

DRUILHE, M. , KHOUDOUR, L. (1987).
Pietons: une si longue attente. (Pedestrians: such a long wait)
TEC No. 84-85, pp. 36-40.

DUPERREX, O., ROBERTS, I., BUNN, F. (2005).
Safety education of pedestrians for injury prevention.
The Cochrane Database of Systematic Reviews (4)
John Wiley & Sons, Ltd

DUSSAULT, C. (1993)
"Safety Effects of Right Turn on Red: A Meta-Analysis".
In: "Proceedings of the Canadian Multidisciplinary Road Safety Conference VIII, June 14-16, 1993, Saskatoon, Saskatchewan, Canada". pp. 427-439

EKMAN, L., DRASKOCSKY, M. (1992)
Trials with Microwave Detection of Vulnerable Road Users and Preliminary Empirical Model Test.
Working Paper No 336
Leeds

ELLIOTT, M. A. (2004)
The attitudes and behaviour of adolescent road users: an application of the theory of planned behaviour.
TRL Report 601

ELLIS,R. , VAN HOUTEN,R. (2008)
Miami Dade Pedestrian Safety Project: Phase II: Final Report and Executive Summary
ERKE.H, GSTALTER,H. (1985)

Verkehrskonflikttechnik Handbuch für Durchführung und Auswertung von Erhebungen
Unfall- und Sicherheitsforschung Strassenverkehr. Bd. 52.
Bremerhaven Wirtschaftsverlag NW

European Transport Safety Council (ETSC) (1999)
Exposure Data for Travel Risk Assessment: Current Practice and Future Needs in the EU
Brussels

European Transport Safety Council (ETSC)(2003)
Transport safety performance in the EU - a statistical overview
Brussels

EVANS, D., NORMAN, P. (1998)
Understanding pedestrians' road crossing decisions: an application of the theory of planned behaviour.
Health Education Research 13 (4), pp. 481-489

Forschungesellschaft Für Straßen- und Verkehrswesen (2002)
Empfehlungen für Fußgängerverkehrsanlagen (EFA)
Köln

Forschungesellschaft Für Straßen- und Verkehrswesen (2001)
Handbuch für die Bemessung von Straßenverkehrsanlagen (HBS)
Köln

Forschungesellschaft Für Straßen- und Verkehrswesen (1998)
Merkblatt für die Auswertung von Straßenverkehrsunfällen; Teil 1: Führen und Auswerten von Unfalltypen-Steckkarten
Köln

Forschungesellschaft Für Straßen- und Verkehrswesen (2003)
Richtlinien für Lichtsignalanlagen (RiLSA)
Köln

Forschungesellschaft Für Straßen- und Verkehrswesen (2010)
Richtlinien für Lichtsignalanlagen (RiLSA)
Scheduled for publication in 2010

Forschungesellschaft Für Straßen- und Verkehrswesen (1988)
Richtlinien für die Anlage von Straßen (RAS)
Teil: Knotenpunkte (RAS-K), Abschnitt 1: Plangleiche Knotenpunkte, RAS-K-1
Köln

Forschungesellschaft Für Straßen- und Verkehrswesen (2006)
Richtlinien für die Anlage von Stadtstraßen (RASt)
Köln

Fortunada (2009)
Retrieved from: http://www.fortunada.com

Frankfurt am Main(2002-2007)
Statistisches Jahrbuch für Frankfurt am Main
Retrieved from: http://www.frankfurt.de/sixcms/detail.php?id=3877

FUNK, W., WIEDEMANN, A. (2002)
Verkehrssicherheitsmaßnahmen für Kinder. BASt-Bericht M 139
ISBN 3-89701-839-X

GARDER, P. (1985)
“Theory for strong validation, application to Swedish results”.
In: “Proceeding from Evaluation 85.International Meeting on the Evaluation of Local Traffic Safety Measures, Paris, France: Organisation National de Securite Routiere”

GARDER, P. (1989)
“Pedestrian Safety At Traffic Signals: A Study Carried Out With The Help Of A Traffic Conflicts Technique”.
Accident Analysis and Prevention 21(5), pp. 435-444

GIBSON, J. J. , CROOKS, L. E. (1938)
A theoretical field-analysis of automobile-driving.
The American Journal of Psychology(51), pp. 453-471

GLAUZ, W. D., MIGLETZ, D. J. (1984)
“The Traffic Conflict Technique of the United States of America”.
In International Calibration Study of Traffic Conflicts, NATO ASI Series Vol. F5, Springer-Verlag, Heidelberg, Germany

GRAYSON, G. (1987)
Pedestrian risk in crossing roads: West London revisited.
Traffic Engineering and Control January, 28(11), pp. 27-30

GREENE-ROESEL, R., CHAGAS, D.M., RAGLAND, D.R.(2007)
Estimating Pedestrian Accident Exposure: Protocol Report
Retrieved from: http://escholarship.org/uc/item/8j8685j

GRIFFITHS,J.D., HUNT,J.G. (1984)
“Delays at pedestrian crossings”.
Traffic engineering and control 25, pp. 365-371

HÄCKELMANN, P. (1976)
Steuerung des Fußgängerverkehrs an Knotenpunkten mit Lichtsignalanlage
Dissertation, Technische Hochschule Darmstadt

HAMED, M.M. (2001)
“Analysis of Pedestrian Behaviours at Pedestrian Crossing”.
Safety Science 38(1), pp. 63-82

HANCOCK, P.A., WULF,G., THOM,D. , FASSNACHT, P. (1990)
“Driver Workload During Differing Driving Manoeuvres”.
Accident Analysis & Prevention 22(3), pp. 281-290

HARKEY, D. L., ZEGEER, C.V. (2004)
PEDSAFE: Pedestrian Safety Guide and Countermeasure Selection System.
U.S. Federal Highway Administration
FHWA-SA-04-003

HARMS, L. (1991)
“Variation in Drivers' Cognitive Load: Effects of Driving Through Village Areas and Rural Junctions”.
Ergonomics 34(2), pp. 151-160

HARRUFF, R.C. (1998)
“Analysis Of Circumstances And Injuries In 217 pedestrian traffic fatalities”.
Accident Analysis & Prevention 30(1), pp. 11-20

HERATY, M. J. (1986)
“Review of pedestrian safety research”.
Transport and Road Research Laboratory

HILLS, B. L. (1980)
Vision, visibility, and perception in driving.
Perception(9), pp.183-216

HINE, J. (1996)
“Pedestrian travel experiences Assessing the impact of traffic on behaviour and perceptions of safety using an in-depth interview technique”.
Joural of Transport Geography 4(3), pp. 179-199

HINE, J. , RUSSEL, J. (1996)
“The impact of traffic on pedestrian behavior2. Assessing the traffic barrier on radial routes”
Traffic engineering and control 37(2), pp. 81-85

HOLLAND, C.A. , HILL, R. (2006)
“Influencing the behaviour of pedestrians when crossing in hazardous situations”.
Internet

HUANG, H.F., CYNECKI, M.J. (2000)
Effects of Traffic Calming Measures on Pedestrian and Motorist Behavior
Transportation Research Record (1705), pp. 26-31

HUANG,H., ZEGEER, C.V. (2000)
The Effects of Pedestrian Countdown Signals in Lake Buena Vista
Prepared for Florida Department of Transportation

HUANG, H. F. , CYNECKI, M. J. (2001)
“The Effect Of Traffic Calming Measures on Pedestrian And Motorist Behaviour
U.S. Federal Highway Administration”.
FHWA-RD-00-104

HUBBEL, ROTH, CLARK (1999)
“Pedestrian Refuge Island” In: “Traffic Tips”

HUPFER,C. (1997)
“Deceleration to safety time (DST) - a useful figure to evaluate traffic safety” .
In: “ICTCT Conference Proceedings of Seminar 3”

HUGHES, C J (1998)
“Pedestrian Safety at Signalised Junctions” . In: “Road Transport Information and Control, 1998.
9th International Conference on (Conf. Publ. No. 454)”. pp.50-54

HUGHES, R., HUANG,H., ZEGEER,C. , CYNECKI, M. (2001)
"Evaluation of Automated Detection at Signalised Intersections".
U.S. Federal Highway Administration
FHWA-RD-00-097

HUMMEL, T. (1999)
"Dutch Pedestrian Safety Research Review".
U.S. Federal Highway Administration
FHWA-RD-99-092

HYDÉN, C. (1987)
The Development of a Method for Traffic Safety Evaluation: The Swedish Traffic Conflicts Technique.
Lund Institute of Technology

Institute of Transportation Engineers (1998)
Design and Safety of Pedestrian Facilities

JACOBS, G. D., WILSON, D. C. (1967)
A study of pedestrian risk in crossing busy roads in four towns.
Laboratory Report 106
TRRL

JAVID,M., SENEVIRATNE ,P. N.(1991)
"Applying Conflict Technique to Pedestrian Safety Evaluation".
ITE Journal, pp. 21-26

JENNINGS, R.D., BURKI, M. A. , ONSTINE., B.W.(1977)
"Behavioural Observations and the Pedestrian Accident".
Journal of Safety Research 9(1), pp. 27-33

KATZ, A., ZAIDEL, D. , ELGRISHI, A. (1975)
"An Experimental Study of Driver and Pedestrian Interaction During the Crossing Conflict".
Human Factors 17(5), pp. 514-527

KEALL, M.D. (1995)
"Pedestrian Exposure to Risk of Road Accident in New Zealand".
Accident Analysis and Prevention 27(5), pp. 729-740

KEEGAN,O., MAHONY,M.O. (2003)
"Modifying pedestrian behaviour".
Transportation Research Part A 37(10), pp. 889-901

KHISTY, C. (1994)
Evaluation of pedestrian facilities: beyond the level-of-service concept
Transportation Research Record (1438), pp. 45-50

KING, W. (1994)
Pelicans, Puffins, and Kiwis.
In: "Conference Proceedings IPENZ Annual Conference, New Zealand, Volume 2"

KNOBLAUCH, R.L.(1975)
“Urban Pedestrian Accident Countermeasures Experimental Evaluation” for the National Highway safety Administration and Federal Highway Administration.

KORDA, C. (1999)
Quantifizierung von Kriterien für die Bewertung der Verkehrsicherheit mit Hilfe digitalisierter Videobeobachtungen
Technischen Universität Darmstadt

LALANI, N. (2001)
Alternative treatments for at-grade pedestrian crossings
ITE Journal ,9, pp. 36-40

LANE, P.L., MCCLAFFERTY, M.J. & NOWAK, E.S. (1996).
“Pedestrians in Real World Collisions.”
The Journal of Trauma, 36, pp. 231-236.

LANGHAM, M. P., MOBERLY, N. J. (2003)
Pedestrian conspicuity research: A review.
Ergonomics(46), pp. 345-363

LI, Q.F., WANG,Z.A., (2005)
“Pedestrian delay estimation at signalised intersections in developing cities”.
Transportation Research Part A 39, pp. 61-73

LORD, D. (1994)
Pedestrian Conflicts and Left-Turning Traffic at Signalised Intersections.
Dissertation, University of Toronto

LORD, D. (1996)
Analysis of Pedestrian Conflicts with Left-Turning Traffic
Transportation Research Record(1538), pp.61-67

LORD, D., A. SMILEY., HAROUN, A. (1997)
“Pedestrian Accidents With Left-Turning Traffic at Signalised Intersections: Characteristics, Human Factors and Unconsidered Issues”.
In: “ TRB 77th Annual Meeting Compendium of Papers CD-ROM”

Mainroad 2009
Retrieved from: http://www.mainroads.wa.gov.au/Pages/Welcome.aspx

MALKHAMAH, S. (1999)
The development of an automatic method of safety monitoring at pelican crossings Dissertation, University of Leeds

MARCAL, S. (1999)
The role of human factors in determining pedestrian risk
PhD Thesis of University of Leeds

MARTIN, A. (2006)
“Factors Influencing Pedestrian Safety: A Literature Review.”
Unpublished Project Report UPR SE/199/05, TRL

MATTHIAS, K.M., ROBERT, F.R. , SCHINDLER,V.(2007)
Fußgängerschutz:Unfallgeschehen, Fahrzeuggestaltung, Testverfahren
Springer Berlin Heidelberg

MENNICKEN, C. (1999)
Sicherheits-und Einsatzkriterien für Fußgängerüberwege
Dissertation, Unversität Hannover

Ministerium für Stadtentwicklung und Verkehr des Landes Nordrhein-Westfalen (1990)
Mehr Sicherheit für Fußgänger an Verkehrsampeln.
Düsseldorf

Metropolitan Transportation Committee in California (MTC),(2009)
Retrieved from: http://www.mtc.ca.gov/

National Center for Statistics and Analysis (2001~2008)
Traffic safety facts
Washington D.C.

National Cooperative Transit Research and Development Program (NCTRP) (2004)
A Guide for Reducing Collisions at Signalised Intersections

NEE, J. , HALLENBECK, M. E. (2003)
A Motorist and Pedestrian Behavioral Analysis Relating to Pedestrian Safety Improvements,
Report No. WA–RD 560.1,
Washington State Department of Transportation.

NGUYEN, A., R AGLAND,D. R.. (2007)
San Pablo Avenue Pedestrian Signal Timing Optimization
In: “ TRB 86th Annual Meeting Compendium of Papers CD-ROM”

NI, Y.(2006)
Investigation of pedestrian behaviour at signalised intersections in Hangzhou
Unpublished Report
Shanghai

OLDER, S. J. , GRAYSON, G.B. (1976)
An international comparison of pedestrian risk in four cities.
TRRL Department of the Environment

OSBORN, R. (1997)
A study of 31 pedestrian fatalities at traffic signal crossroads.
Unpublished Project Report PR/TT/073/97.
TRL

Organisation for Economic Co-operation and Development (OECD) (1997)
Safety of Vulnerable Road User

OXLEY J., FILDES B., IHSEN E., CHARLTON J., DAY R(1997)
“Differences in Traffic Judgements Between Young And Old Adult Pedestrians”.
Accident Analysis & Prevention 29(6), pp. 839-847

PARKER, M. R. ,ZEGEER,C.V. (1989)
Traffic Conflict Techniques for Safety and Operations: Observers Manual
U.S. Federal Highway Administration
FHWA-IP-88-027

PERKINS, S. R., HARRIS, J. L. (1968)
Traffic Conflict Characteristics: Accident Potential at Intersections.
In Highway Research Record 225, pp. 35–44
National Research Council
Washington, D.C.

PFUNDT, K.,MEEWES,V.,MAIER,R. (1985)
Einige Bemerkung zur Verkehrskonflikttechnik
Zeitschrift für Verkehrssicherheit 32, pp. 39-46

Planungsamt Der Oberstadtdirektor der Stadt Aachen Baudezernat(1989)
Sicherheit für Fußgänger an lichtzeichen geregeltenVerkehrsknoten.
Aachen

PTV (2009)
Retrieved from: http://www.ptvag.com/software/transportation-planning-traffic engineering/software-system-solutions/public-safety/euska/

PUCHER, J. & DIJKSTRA, L. (2000)
"Making Walking and Cycling Safer: Lessons from Europe".
Transportation Quarterly 54(3), pp. 25-50

PUCHER, J. & DIJKSTRA, L. (2003)
"Promoting Safe Walking and Cycling to Improve Public Health: Lessons from the Netherlands and Germany".
American Journal of Public Health 93, pp. 1509-1516

PRESTON, B. (1989)
"The behaviour and safety of pedestrians at Pelican crossings in Greater Manchester".
Traffic engineering and control 20 (12), pp. 596-599

PREUSSER, D.F., LEAF, W.A., DEBARTLA, K.B. , BLOMBERG, R.D. (1981)
The Effects of Right-Turn-on-Red on Pedestrian and Bicycle Accidents.
Report No. NHTSA-DOT/HS-806/182.

QUAYE, K., LARSDEN, L. , HAUER, E. (1993)
Pedestrian Accidents and Left-Turning Traffic at Signalised Intersections
University of Toronto, Canada

RALPH, E.R., VAN HOUTEN, R.(2008)
MiamiDade Pedestrian Safety Project: Phase II Final Implementation report and executive summary
FDOT-BD545-02

RETTING, R.A., NITZBURG, M.S., FARMER, C.M. AND KNOBLAUCH, R.L.(2002)
"Field evaluation of two methods for restricting right turn on red to promote pedestrian safety".
ITE Journal ,72, pp.32-35

RETZKO, H.-G, P. HÄCKELMANN, P. (1977)
"A quantified description of risky pedestrian behaviour at signalised intersections"
In: "Proceedings of the Seventh International Symposium on Transportation and Traffic Theory"

ROBERTS, I, NORTEN, R. , TAURA., B. (1996)
Child Pedestrian Exposure Rates: The Importance of Exposure to Risk Relating to Socioeconomic and Ethnic Differences in Auckland, New Zealand.
Journal of Epidemiology and Community Health 50(2), pp. 162-165

ROBERTSON, H.D., CARTER, E.C. (1984)
"The Safety, Operation, and Cost Impacts of Pedestrian Indications at Signalised Intersections".
Transportation Research Record ,(959), pp.1-7

ROBERTS, C. (1997)
A comparison of pedestrian accident rates in Europe and North America.
TRL Unpublished Report PR/TT/093/1997.
TRL

ROBINSON, B. J. (1997)
"Fatal Accidents Involving Heavy Goods Vehicles in Great Britain, 1991-1993" .
In: "30th International Symposium on Automotive Technology and Automation"

ROUPHAIL, N. (1984),
"Mid-Block Crosswalks: A User Behavior and Preference Study".
Transportation Research Record (959), pp. 41-47.

ROUPHAIL, N., HUMMER, J., MILAZZO II, J., ALLEN,P. (1998)
"Capacity Analysis of Pedestrian and Bicycle Facilities: Recommended Procedures for the Signalised Intersections".
U.S. Federal Highway Administration
FHWA-RD-98-106

ROSENSTOCK, I.M., STRECHER, V.J. , BECKER, M.H. (1988)
Social learning theory and the Health BeliefModel.
Health Education Quarterly(15), pp. 175-183

RUSSEL, J. HINE, J. (1996)
"The impact of traffic on pedestrian behaviour1. Measuring the traffic barrier"
Traffic engineering and control 37(1), pp. 16-18

SANCA, M. (2002)
"Application of design for safer urban roads and junctions: selected countermeasures".
Linkoping University, Sweden.

SARKAR, S.(1993)
Determination of Service Levels for Pedestrians,With European Examples.
Transportation Research Record 1405, pp.35-42.

San Francisco Municipal Transportation Agency (SFMTA) , the University of California, Berkeley Traffic Safety Center (TSC) (2008)
San Francisco Pedestrian Safety Project: Phase II: Final Report and Executive Summary

SARAN ,M. L., HUBBARD, P., BULLOCK , D.M., THAI, J.H.(2008)
Trial Implementation of a Leading Pedestrian Interval : Lessons Learned
ITE Journal ,78, pp. 32-41

Shanghai (2002-2007)
Retrieved from: http://www.stats-sh.gov.cn

SIMMONDS, A. G. (1983)
The effects of erection of guard rail.
LAAU Road Safety Unit Report ATWP 77
London Accident Analysis Unit.

SISIOPIKU, V. P., AKINB, D. (2003)
"Pedestrian behaviors at and perceptions towards various pedestrian facilities: an examination based on observation and survey data".
Transportation Research Part F, 6, pp. 249-274

SMEED, R.J. (1968)
Aspects of pedestrian safety
Journal of Transport Economics and Policy, 2(3),pp. 255-279

SPICER, B.R (1973)
"A Study of Traffic Conflict at Six Intersections".
Transportation and Road Research Laboratory
Report LR551

Statistischen Bundesamtes Deutschland (1975~2008)
Statistisches Jahrbuch

STEWART, D. (1991)
"Driver Perceptual Error and Child Pedestrian Accidents".
In: "Vision in Vehicles III"

StVO (1997)
Straßenverkehrs-Ordnung (StVO) und Allgemeine Verwaltungsvorschrift zur Straßenverkehrs-Ordnung (VwV-StVO)
Dortmund

SUN, S.J., WANG, C., ZHANG,Y. (2007)
"Psychological Research on Pedestrian Violations at Urban Road Intersections"
Urban Traffic of China 30 (5), pp. 92-98

Tfhrc (2009)
Retrieved from: http://www.tfhrc.gov/safety/pedbike/pubs/05085/pptchapt23.htm

THOMPSON, S.J., HOWARTH,C.J.(1985)
"Driver Behaviour in the Presence of Child and Adult Pedestrians".
Ergonomics 28(10), pp. 1469-1474

TIWARI, G.D. MOHAN, J. F. (1998)
"Conflict Analysis For Prediction Of Fatal Crash Locations In Mixed Traffic Streams".
Accident Analysis & Prevention 30(2), pp. 207-215

THOMSON, J. A., WHELAN, K. M. (1997)
A community approach to road safety education using practical training methods.
Road Safety Research Report No. 3.
The Department of Transport
London

TOURINHO, L.F.B., PIETRANTONIO, H. (2003)
"Parameters For Evaluating Pedestrian Safety Problems In Signalised Intersections Using the Traffic Conflict Analysis Technique: A Study In Sao Paolo, Brazil".
Transportation planning and technology, 29, pp. 183-216.

Traffic Administration Bureau of China State Security Ministry (2000~2007)
Report of China Road Traffic Accidents Statistics (CRTAC)

Transportation Research Board (2000)
Highway Capacity Manual (HCM)
Washington D.C.

Transportation Research board (2005)
Evaluate the Effect of Pedestrian Safety Sting Operations on Motorist Yielding Behavior
Internet

Transportation Research board (2009)
Retrieved from: http://rns.trb.org/dproject.asp?n=14160

U.K. Department of Transport (1987)
Killing Speed and Saving Lives
London

UK Department of Transport (1993)
Network Management Advisory Leaflet: The Use of Puffin Pedestrian Crossings.

UK Department of Transport (1995)
The Design of Pedestrian Crossings

UK Highway Code (2009)
Retrieved from: http://www.direct.gov.uk/en/TravelAndTransport/Highwaycode/index.htm

U.S. Federal Highway Administration (2003)
Manual on Uniform Traffic Control Devices

U.S. Federal Highway Administration (2006)
FHWA University Course on Bicycle and Pedestrian Transportation
FHWA-HRT-05-065

U.S. Federal Highway Administration (2008)
Pedestrian Safety: Report to Congress

VAN HOUTEN, R., MALENFANT, J.E. L. (1999)
Canadian Research on Pedestrian Safety,
U.S. Federal Highway Administration
FHWA-RD-99-090

VAN HOUTEN, R., RETTING, R. A., FARMER, C. M. ,VAN HOUTEN,J. (2000)
"Field Evaluation of a Leading Pedestrian Interval Signal Phase at Three Urban Intersections"
Transportation Research Record (1734), pp. 86-92

VAZIRI, B (1996)
"Exclusive Pedestrian Phase for the Business District Signals in Beverly Hills, 10 Years Later".
Internet
Verkehrstechnisches Institut der Deutschen Versicherer (2004)
Schulwegsicherung (2004) Informationen für Eltern: Schulwegsicherung
Berlin

Verkehrswacht (2009)
Retrieved from: verkehrswacht.heidenheim.com/html/presse.htm

VERMEULEN, W. (1998)
"PROMISING- Review of Measures Promoting Safety of Pedestrians".
De Voetgangersvereniging, Hague. Netherlands

VIRKLER, M. R. (1998)
Scramble and Crosswalk Signal Timing
Transportation Research Record (1636), pp. 83-87

VIRKLER, M. R. (1998)
Pedestrian Compliance Effects on Signal Delay
Transportation Research Record(1636), pp. 88-91

VON STEIN, W. (1976)
Überwegsignale mit Gelb für die Füßgänger
Polizei+Verkehrsjoural(2), pp. 1-8

WIDBUCH, R. (1989)
Kriterien für die Gestaltung,Einsatz und Sicherheit von alternativen Fußgängerüberwegen,
Forschungsbericht der Bundesanstalt für Straßenwesen, Bereich Unfallforschung, Heft 208.
Bundesanstalt für Straßenwesen

Wiki (2009)
Retrieved from: http://en.wikipedia.org

WILLIAMS, M. J. (1981)
Validity of the Traffic Conflicts Technique.
Accident Analysis & Prevention, 13(2), pp. 133–145

WOLFFELAAR, P.C. VAN (1988).
Elderly Traffic Participants: Traffic Problems and Educational Objectives
Rijksuniversiteit Groningen, Netherlands.

XIONG, H., WU, J.P.(2008)
"Disaggregate Model for the preference of pedestrian's Crossing Facilities selection"
Transactions of Beijing Institute of Technology 28, pp. 37-40

YAGIL, D. (2000)
Beliefs, motives and situational factors related to pedestrians' self-reported behavior at

signal-controlled crossings
Transportation Research Part F 3, pp. 1-13

YANG, J.G., LI, Q.F. (2005)
"Estimating pedestrian delays at signalised intersections in developing cities by Monte Carlo method".
Mathematics and Computers in Simulation 68(4), pp. 329 -337

YANG, J.G., DENG, W. (2006)
"Modeling pedestrians road crossing behaviour in traffic system micro-simulation in China".
Transportation Research Part A 40, pp. 280-290

ZAIDEL, D. M., HOCHERMAN, I.(1987)
Safety of Pedestrian Crossings at Signalized Intersections.
Transportation Research Record 1141, pp. 1–6

ZEGEER, C.V., CYNECKI, M. J. , OPIELA, K.S.(1984)
Evaluation of Innovative Pedestrian Signalisation Alternatives
Transportation Research Record (959), pp. 7-18

ZEGEER, C.V., OPIELA, K.S. , CYNECKI ,M.J. (1982)
Effect of Pedestrian Signals and Signal Timing on Pedestrian Accidents
Transportation Research Record 847,pp. 62-72

ZEGEER, C.V., OPIELA K.S. ,CYNECHI, M.J. (1985)
"Pedestrian Signalisation Alternatives "
U.S. Federal Highway Administration
FHWA/RD-83/102

ZEGEER, C.V. (1988)
Pedestrians and traffic control measures
Synthesis of Highway practice, No. 139
Transportation Research Board

ZEGEER, C.V., CYNECKI, M., FEGAN, J., GILLERAN, B., LAGERWEY, P., TAN, C., WORKS, B. (1994)
FHWA Study Tour for Pedestrian and Bicyclist Safety in England, Germany, and The Netherlands.
Report FHWA-PL-95-006.
Federal Highway Administration

ZEGEER, C.V. ,SEIDERMAN, C.(2001)
"Designing for Pedestrians".
In: " 2001 Compendium of Technical Papers, ITE, 71st Annual Meeting, Chicago".

ZHAO, J.L., WU,J.P. (2003)
"Analysis of Pedestrian Behavior With Mixed Traffic Flow at Intersection".
In: "Intelligent Transportation Systems, 2003. Proceedings".
Institute of Transportation Engineers (1998)
Design and Safety of Pedestrian Facilities

ZHENG,P., HALL, R.D. (2003)
Pedestrian Guard Railing: A Review of Criteria for Installation
University of Southampton

A Pedestrian accident analysis (Darmstadt, 2001-2005)

A.1 Introduction of pedestrian accidents database

A.1.1 Accidents database

The accidents database included all accidents which happened at signalised intersections of inner city in Darmstadt from 2001 to 2005.Meanwhile the pedestrian accidents data could be selected out. Related information can be available from accidents databank and the accidents diagrams.

- conditions of intersections
    - names and grades of intersecting roads
    - location in the road network
    - reconstructed or not
    - land use
    - traffic related facilities in the area of the intersection(such as train station, hotel, etc)
    - trams or busses passing intersections
    - tram stations or bus stops in the area of intersections
    - permitted highest speed on the main road
    - general description of pedestrian and cycle traffic (whether exist/with high volume)
    - control strategy (within the green wave or not)
    - public transport acceleration(transit signal priority)
    - red light monitoring
    - signal for sight-handicapped
    - information about traffic signal controller
    - etc.
- accidents list
    - date
    - time
    - location of accidents
    - accident consequences (with persons injuries, fatalities, with persons severe injuries, with persons slight injuries) and accident costs
    - types of accidents
    - reasons for accidents (reasons, drunk/escape, lighting conditions, pavement conditions)
    - special involvements in the accidents
    - (pedestrian, cycle, motorcycle ,public transport vehicle, child, animal)
    - etc.
- evaluation of safety situation of intersections
    - main types of accidents in the intersection
    - safety level of the intersection
    - etc.
- Accidents diagrams

- basic layout of intersections
- location of pedestrian accidents
- lighting and pavement conditions
- age of involved pedestrians
- colour of signal when accidents related pedestrians walking
- type of involved vehicles
- severity of pedestrian accidents
- etc.

A.1.2 Deficiencies of the database

The deficiencies of data base include:

- Lack of information of exact **traffic volumes** when accidents happened;
- Lack of information of **layout and signal program** of intersections when accidents happened;
- Only age information can be acquired partly from accident diagrams ,lack of **other demographic information** about pedestrians involved in the accidents;
- Exact relation between pedestrian accidents and the time when pedestrians enter the crosswalk in the cycle is difficult to establish;
- Relation between pedestrian accidents and the waiting time of pedestrians involved in the accidents is difficult to establish;

A.2 Analysis of pedestrian accidents in Darmstadt

A.2.1 Overview

Statistic data of accidents happened at signalised intersections of inner city in Darmstadt from 2001 to 2005 was collected. In the past 5 years,5355 accidents happened and 193 of which happened with pedestrians， 11 persons were killed and 5 of them were pedestrians, 200 persons were severely injured and 50 of them were pedestrians. The fact has indicated that though pedestrian accidents only took a very small share of total accidents (3.60%), the consequences of pedestrian accidents were much more serious, pedestrian accidents took 45.45% of total fatalities and 25% of severe injuries.

Table 1: Number and consequences of total accidents and pedestrian accidents (2001~2005)

	accidents	accidents with person- injures	fatalities	Severe injuries	slight injuries
total	5355	1639	11	200	2085
pedestrians	193	170	5	50	143
pedestrians / total	**3.60%**	**10.37%**	**45.45%**	**25.00%**	**6.86%**

According to Table 1, in the **193 pedestrian accidents**, there were **170 accidents with person- injurie**s and **198 pedestrians** were involved, in which **5 were killed**, **50 were severely injured and 143 were slightly injured.** In another word, 1 fatality, 10 severe injuries and 29 slight injuries happened within average year.

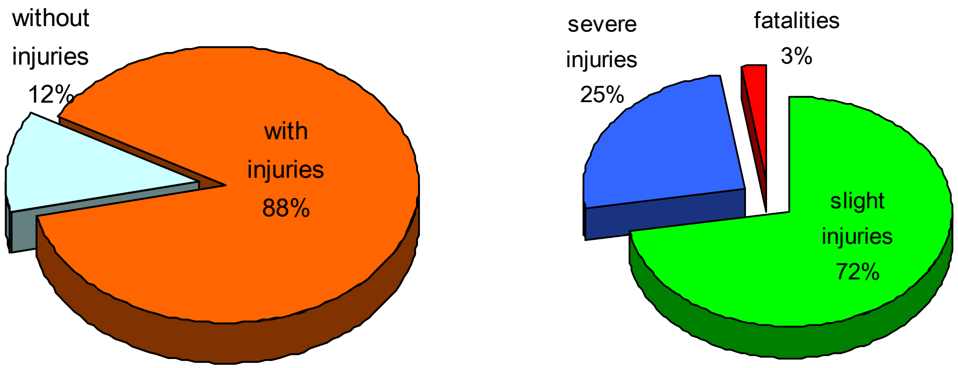


Figure 1: Consequence of pedestrian accidents in Darmstadt

(193 accidents,189 involved pedestrians)

In the 198 injured or killed pedestrians, 34 were children, which took a proportion of 17%.

A.2.2 Pedestrian accident characteristics

Accidents distribution of time

The accidents distribution of time, including month, day and period of day were analysed according to the 193 accidents.

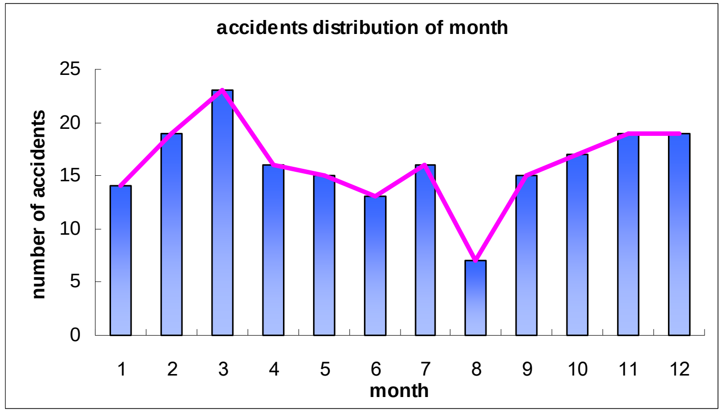


Figure 2: Accidents distribution of month

Accidents happened more often in winter times (October until March) than in summer times (April until September). March is the month with most accidents while August with the fewest.

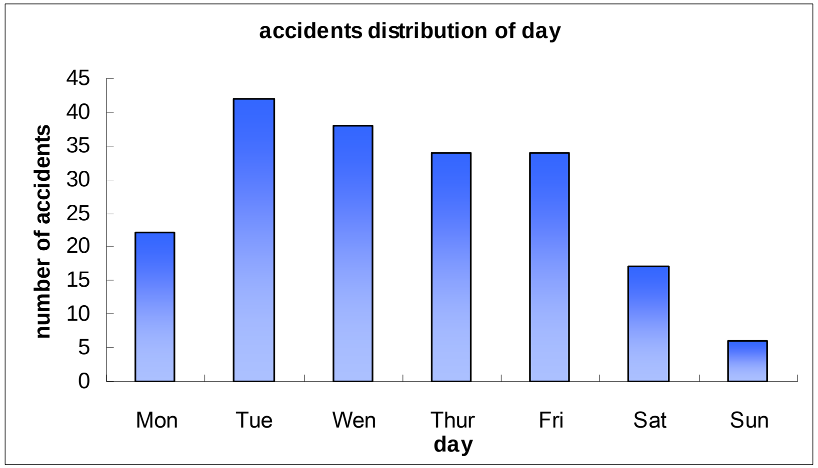


Figure 3: Accidents distribution of day

Accidents happened more often on workdays than weekend, especially on **Tuesdays**.

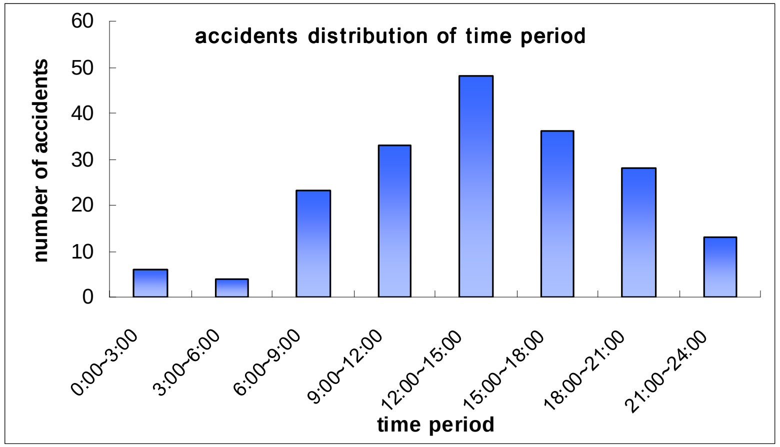


Figure 4: Accidents distribution of time period

The majority of accidents happened during the period of 6:00~24:00 within a day, and the most concentrated period of accidents is 12:00~15:00, which weren't the regular peak hours. Accidents distribution of location

Intersections with three or more pedestrian accidents happened in the successive five years or two and more in the same year were selected as "accident black spots".

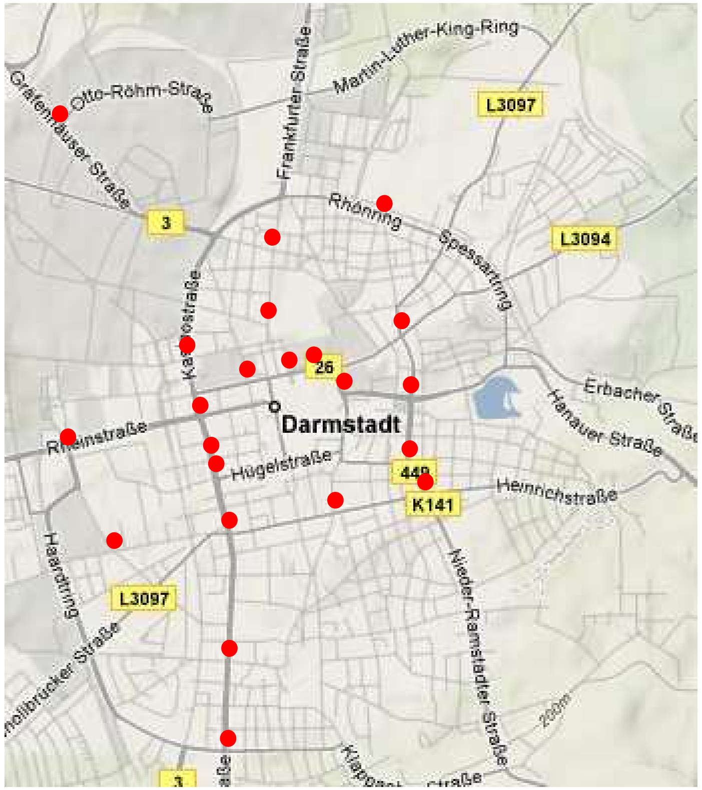


Figure 5: Pedestrian accident black spots in Darmstadt

According to the distribution of accident black spots, most of the accidents happened at intersections along the main roads in the core area of the city with high speeds of motorised vehicles ,a large number of public transport vehicles passing and tram stations or bus stops in the area of intersections, such as longitudinal roads of Heidelbergstraße (Neckarstraße,Kasinostraße) and Teichhausstraße, vertical roads of Rheinstraße and Heinrichstraße.

Accidents distribution of lighting conditions

The majority of accidents happened under daylight and a quarter of the accidents happened in the dark but with the severest consequences. Only a few accidents happened during dawn.

Table 2: Accidents distribution of lighting conditions

lighting conditions	proportion of number of accidents	average accidents cost (1000€)
daylight	69.43%	54
dark	25.91%	63
dawn	4.66%	15

Note:
1.“accident cost” has been used to indicate the severity of the accident;
2. accident cost=160000*SP+12500*LV
3. SP: number of fatalities and persons with severe injuries;
4. LV: number of persons with slight injuries.

Accidents distribution of pavement conditions

Very few accidents happened on roads with ice but the consequence is nearly 2 times severer than accidents happened on dry or wet roads.

Table 3: Accidents distribution of pavement conditions

pavement conditions	proportion of number of accidents	average accidents cost (1000€)
dry	74.61%	57
wet	23.83%	47
with ice	1.55%	120

Accidents types

- **Related vehicle types**

85% of the 193 accidents took place between pedestrians and ordinary cars, while 7% related to public transport vehicles (trams:4%,buses:3%) ,and meanwhile, the other 3% and 5% related to motorcycles and cycles.

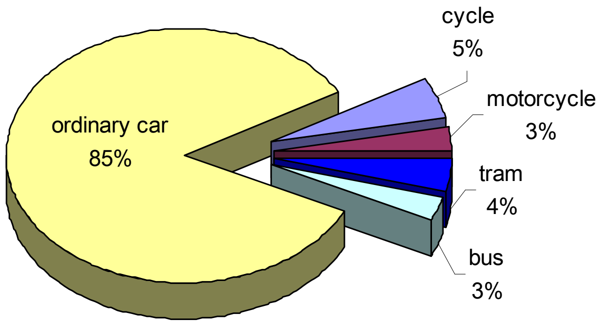
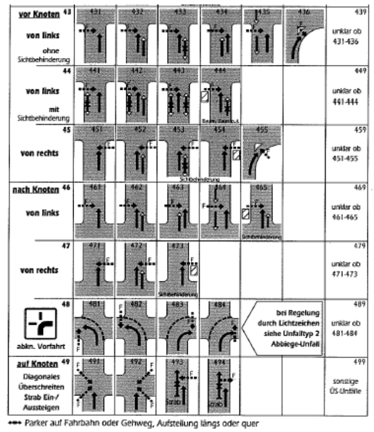
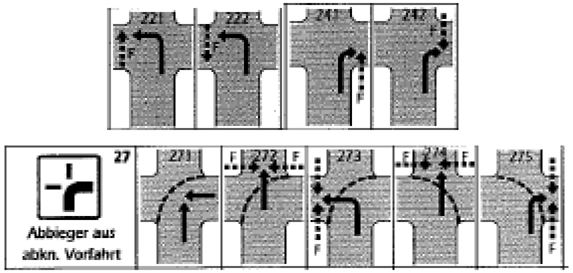


Figure 6 : Types of related vehicles in pedestrian accidents

- **Accidents types**



(a) Street crossing accidents



(b) Accidents related to the turning traffic

Figure 7: Two main types of pedestrian accidents (FGSV, 1998)

Generally speaking, there were two main types of pedestrian accidents: pedestrians crashing with through vehicles (ÜS) and with turning vehicles (AB).The former one took the majority (76.17%) and also had a severer consequence when happened.

Table 4: Accidents types

type	proportion of number of accidents	average accidents cost (1000€)
crash with through driving vehicles	76.17%	55
crash with turning vehicles	15.03%	51
others	8.80%	65

When dividing the types of pedestrian accidents in more details according to factors such as walking directions of pedestrians, directions of turning vehicles and exact locations of accidents etc, 6 main types of accidents could be described as follows.

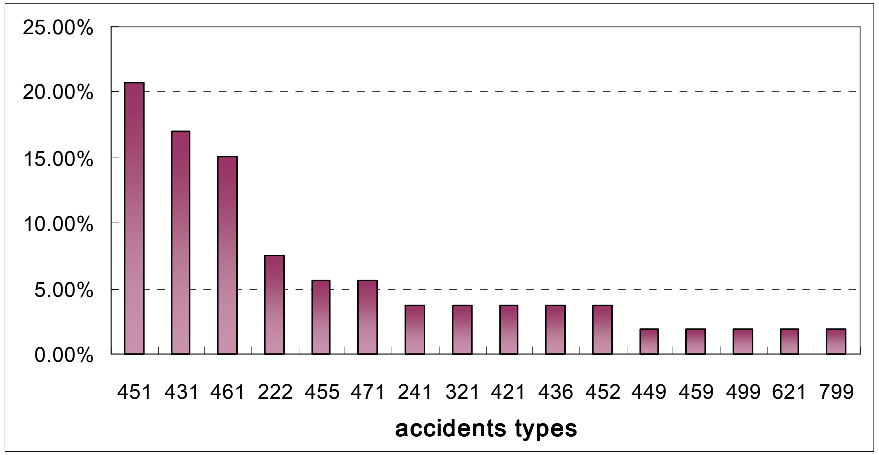
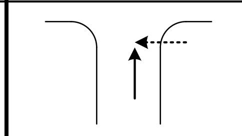
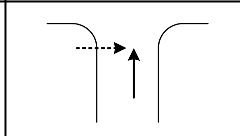
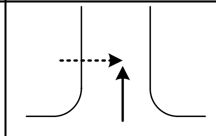
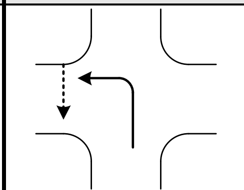
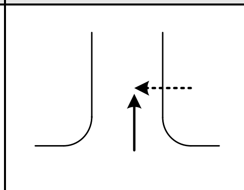
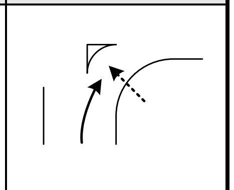


Figure 8: Pedestrian accidents types in details

Table 5: main types in details of pedestrian accidents

type	451	431	461
			
proportion	20.75%	16.98%	15.09%
type	222	455	471
			
proportion	7.55%	5.66%	5.66%
Note:	*pedestrians* (dashed arrow)	*motorised vehicles* (solid arrow)	

Accidents reasons

According to the accident reasons recorded by the police, main reasons for accidents with fatalities and severe injuries and reasons for all pedestrian accidents were found out.

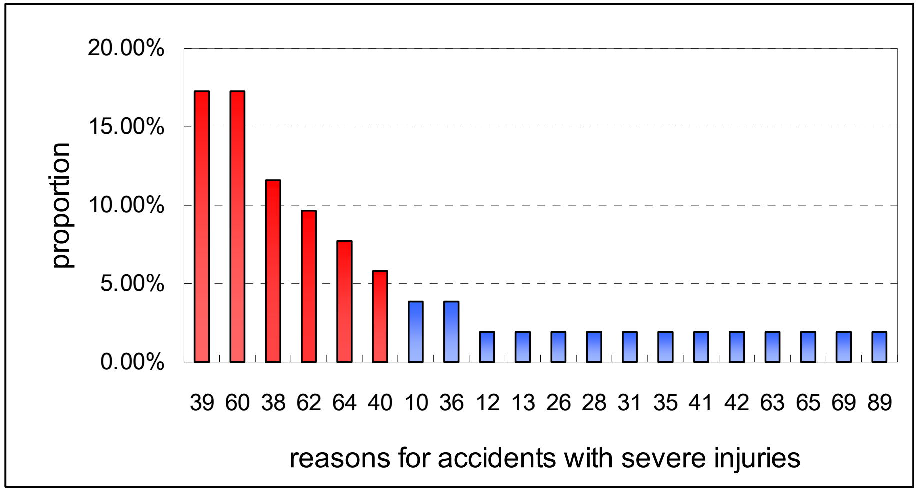


Figure 9: Reasons for accidents with fatalities and severe injuries

There were **6 main reasons for severe accidents and two most important reasons related to drivers and pedestrians individually.** On one hand, drivers behaved improperly towards pedestrians at signalised intersections, such as not paying attention to pedestrians, not yielding to pedestrians etc, and on the other hand, pedestrians either didn't behave properly when crossing at signalised intersections, the common improper behaviour was violating signals.

Table 6: Main reasons for accidents with fatalities and severe injuries

number of reasons	reasons	proportion
39	improper behaviours of drivers towards pedestrians at signalised crossings	17.31%
60	improper behaviours of pedestrians when crossing at signalised intersections	17.31%
38	improper behaviours of right turning drivers towards pedestrian at zebra crossings	11.54%
62	improper behaviours of pedestrians crossing near intersections, without using the signalised crossings	9.62%
64	pedestrians without paying attention to traffic	7.69%
40	improper behaviours of drivers while turning	5.77%

And for all accidents, there were still 6 main reasons the same as them for severe accidents, but the most important reasons are different. Pedestrians' improper behaviours at signalised intersections and their lacking of paying attention to traffic took the responsibility of more than 30%.

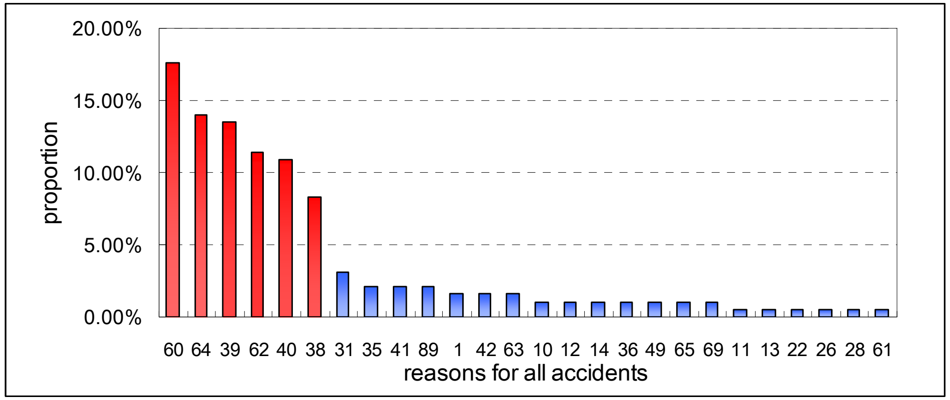


Figure 10: Reasons for all pedestrian accidents

Table 7: Main reasons for all pedestrian accidents

reason code	definition of reasons	proportion
60	improper behaviours of pedestrians when crossing at signalised intersections	17.62%
64	without paying attention to traffic	13.99%
39	improper behaviours of drivers towards pedestrians at signalised crossings	13.47%
62	improper behaviours of pedestrians crossing near intersections, without using the signalised crossings	11.40%
40	improper behaviours of drivers while turning	10.88%
38	improper behaviours of right turning drivers towards pedestrian at zebra crossings	8.29%

A.3 Conclusions

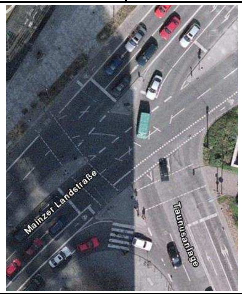
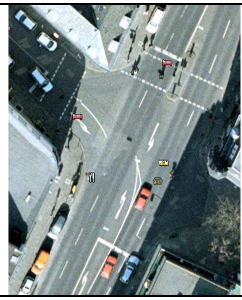
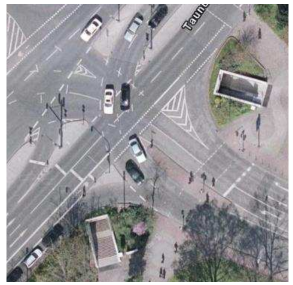
According to the analysis of 193 pedestrian accidents in Darmstadt, preliminary conclusions can be drawn as follows:

- Pedestrians are the most vulnerable participants of traffic at the intersections. The fewest accidents lead the severest consequence, so taking more particular consideration of the safety of pedestrians is very necessary.
- Pedestrian accidents happened more often at winter season, on workdays especially Tuesday and during the period of 12:00~15:00.
- Pedestrian accidents happened more often at intersections along the main roads in the core area with high speeds of motorised vehicles, large numbers of public transport vehicles and tram stations or bus stops.
- Consequences of pedestrian accidents happened in the dark or on icy roads were much severe than normal ones.
- Accidents happened more often between pedestrians and through driving vehicles, the 6 main pedestrian accidents types were: crashes at the entrance lanes between through driving vehicles and entering pedestrians from right and left; crashes at the exit lanes between vehicles and entering pedestrians from left and right; crashes between left turning vehicles and pedestrians entering in the opposite direction; crashes between right turning vehicles and pedestrians entering the triangular island.
- Pedestrians' violation and lack of paying attention to traffic are the most important reasons for pedestrian accidents.
- Pedestrians and drivers nearly share the same responsibility of severe accidents.

B Investigated crossings in Germany

B.1 Intersection geometry and layout design

Table 8: Intersection geometry and layout design of investigated crossings in Germany

serial number	F(2,2,1)	F(2,2,0)	D(2,2,0)	D(3,2,1)	D(2,2,1)	F(3,3,1)	F(3,2,1)-1	F(3,2,1)-2
name of intersection	Taunusanlage - Mainzer Landstraße	Taunusanlage - Mainzer Landstraße	Oststraße - Steinstraße	Oststraße - Steinstraße	Oststraße-Bahnstraße	Taunusanlage - Bockenheimer Landstr	Taunusanlage - Junghofstraße	Berlinerstraße -Hasengasse
type of intersections	T	T	X	X	X	T	T	X
crossing location	Taunusanlage	Mainzer Landstraße	Steinstraße	Oststraße	Oststraße	Taunusanlage	Junghofstraße	Berlinerstraße
road grade	main	minor	main	main	main	main	minor	main
picture								
road width (m)	19.5	12	12	16.5	16.5	29	18	16.5
With bicycle lanes	yes	no	no	no	no	yes	no	no
width of bicycle lane(m)	2	-	-	-	-	1.85	-	-
curb radius(m)	15	15	<15	<15	10	<15		<15
triangular islands	yes	yes	no	no	no	no	no	no

B.2 Signal control

Table 9: Signal control parametres of investigated crossings in Germany

serial number		F(2,2,1)	F(2,2,0)	D(2,2,0)	D(2,2,1)	F(3,2,1)-1	F(3,2,1)-2	D(3,2,1)	F(3,3,1)
crossing location		Taunusanlage	Mainzer Landstraße	Steinstraße	Oststraße	Junghofstraße	Berlinerstraße	Oststraße	Taunusanlage
pedestrian push button		yes	no	no	no	no	no	no	yes
cycle length (s)		90	90	70	70	90	90	70	90
pedestrian red time(s)	near side	84	60	50	33	76	67	26	79
	far side	77			38	55	60	26	77
pedestrian green time(s)	near side	6	30	10	32	14	23	38	11
	far side	13			27	35	30	38	13
signal of pedestrian clearance time		Red	Red	Yellow	Yellow	Red	Red	Yellow	Red
right-turn phasing		permissive	protected	protected	permissive	permissive	protected	protected	lagging permissive
left-turning phasing		protected	protected	lagging permissive	protected	lagging permissive	protected	protected	lagging permissive
signalisation at successive crossing		separate	-	-	separate	separate	simultaneous	simultaneous	simultaneous

B.3 Pedestrian and driver behaviour

B.3.1 Pedestrian types

F(2,2,0)	arrive at the curb side			
start from the curb side	G	CT	R	sum
GW	72	2	84	158
LW	0	9	0	9
RW	0	0	37	37
EW	0	0	18	18
sum	72	11	139	222

F(2,2,1)	arrive at the curb side			
start from the curb side	G	CT	R	sum
GW	17	0	83	100
LW	0	5	0	5
RW	0	0	12	12
EW	0	0	8	8
sum	17	5	103	125

D (3,2,1)	arrive at the curb side			
start from the curb side	G	CT	R	sum
GW	92	4	51	147
LW	0	5	0	5
RW	0	0	16	16
EW	0	0	1	1
sum	92	9	68	169

D (3,2,1)	arrive at the refuge island			
start from the refuge island	G	CT	R	sum
GW	138	6	6	150
LW	0	10	0	10
RW	0	0	6	6
EW	0	0	3	3
sum	138	16	15	169

F(3,2,1)-2 far side to near side	arrive at the curb side			
start from the curb side	**G**	**CT**	**R**	sum
GW	14	4	35	53
LW	0	2	0	2
RW	0	0	13	13
EW	0	0	3	3
sum	14	6	51	71

F(3,2,1)-2 far side to near side	arrive at the refuge island			
start from the refuge island	**G**	**CT**	**R**	sum
GW	60	0	2	62
LW	0	3	0	3
RW	0	2	3	5
EW	0	0	1	1
sum	60	5	6	71

F(3,2,1)-2 near side to far side	arrive at the curb side			
start from the curb side	G	CT	R	sum
GW	18	2	40	60
LW	0	1	0	1
RW	0	0	14	14
EW	0	0	0	0
sum	18	3	54	75

F(3,2,1)-2 near side to far side	arrive at the refuge island			
start from the refuge island	G	CT	R	sum
GW	58	1	2	61
LW	0	2	0	2
RW	0	0	12	12
EW	0	0	0	0
sum	58	3	14	75

F(3,3,1) far side to near side	arrive at the curb side			
start from the curb side	G	CT	R	sum
GW	18	2	57	77
LW	0	1	0	1
RW	0	0	0	0
EW	0	0	0	0
sum	18	3	57	78

F(3,3,1) far side to near side	arrive at the refuge island			
start from the refuge island	G	CT	R	sum
GW	0	22	12	34
LW	0	41	0	41
RW	0	1	2	3
EW	0	0	0	0
sum	0	64	14	78

F(3,3,1) near side to far side	arrive at the curb side			
start from the curb side	G	CT	R	sum
GW	4	3	53	60
LW	0	7	0	7
RW	0	0	4	4
EW	0	1	1	2
sum	4	11	58	73

F(3,3,1) near side to far side	arrive at the refuge island			
start from the refuge island	G	CT	R	sum
GW	44	1	2	47
LW	0	22	0	22
RW	0	0	4	4
EW	0	0	0	0
sum	44	23	6	73

B.3.2 Interactions and conflicts

Besides the following two crossings, there are no interactions/conflicts happened at the other crossings during observation periods.

F(3,2,1) at far side	level 0	level1	level 2a	level 2b
GW	9	12	-	-
LW	-	-	0	0
RW	-	-	0	0
EW	-	-	0	0

F(3,2,1) at near side	level 0	level1	level 2a	level 2b
GW	0	0	-	-
LW	-	-	0	4
RW	-	-	2	0
EW	-	-	0	0

D (3,2,1)	level 0	level1	level 2a	level 2b
GW	31	9	-	-
LW	-	-	0	0
RW	-	-	1	0
EW	-	-	0	0

C Investigated crossings in China

C.1 Intersection geometry and layout design

Table 10: Intersection geometry and layout design of investigated crossings in China

serial number	S(2,2,0)-1	S(2,2,0)-2	S(2,2,0)-3	S(3,2,0)-1	S(3,2,0)-2	S(4,2,0)	S(4,3,0)	S(4,3,1)
name of intersection	Kongjiang Road- Anshn Road	Quyang Road-Yutian Road	Chifeng Road-	Guangfu Road-Yuling Road	Baoshan Road-Wuning Road	Daduhe Road-Guangfu Road	Changshou Road-Wuning Road	Dalian Road-Feihong Road
type of intersections	T	X	X	X	X	X	X	X
crossing location	Anshn road	Quyang road	Chifeng Road	Guangfu Road	Baoshan Road	Daduhe Road	Wuning Road	Dalian Road
road grade	main	main	main	minor	main	main	main	main
road width (m)	21	22	33	30	30	33	40	33
With bicycle lanes	yes	yes	yes	yes	yes	yes	yes	yes
curb radius(m)	<15	15	30	30	>25	30	>25	>25
triangular islands	no	no	no	no	yes	no	no	no

C.2 Signal control

Table 11: Signal control parametres of investigated crossings in China

serial number	S(2,2,0)-1	S(2,2,0)-2	S(2,2,0)-3	S(3,2,0)-1	S(3,2,0)-2	S(4,2,0)	S(4,3,0)	S(4,3,1)
cycle length (s)	108	120	75	112	223	200	236	220
pedestrian red time(s)	80	91	42	69	113	139	192	138/172
pedestrian green time(s)	11	29	16	37	92	45	10	70/35
signal of pedestrian clearance time	FG	no	FG	FG+DARK	FG+CD	FG+CD	FG+CD	FG
pedestrian clearance time	17	0	17	3+3	18	16	34	13/13
right-turn phasing	permissive	permissive	permissive	permissive	permissive	protected	permissive	protected
RTOR	yes	yes	yes	no	yes	no	no	yes
left-turning phasing	permissive	protected	permissive	protected	protected	protected	protected	permissive
signalisation at successive crossing	-	-	-	-	-	-	-	separate
remarks		countdown signal during Red						

C.3 Pedestrian and driver behaviour

C.3.1 Pedestrian types

S(2,2,0)-1	arrive at the curb side			
start from the curb side	G	CT	R	sum
GW	92	2	211	305
LW	5	94	3	102
RW	2	0	207	209
EW	0	0	63	63
sum	99	96	484	679

S(2,2,0)-2	arrive at the curb side			
start from the curb side	G	CT	R	sum
GW	83	76	0	159
LW	0	0	0	0
RW	85	0	0	85
EW	38	0	0	38
sum	206	76	0	282

S(2,2,0)-3	arrive at the curb side			
start from the curb side	G	CT	R	sum
GW	149	67	1	217
LW	0	0	32	32
RW	1	0	0	1
EW	14	0	0	14
sum	164	67	33	264

S(3,2,0)	arrive at the curb side			
start from the curb side	G	CT	R	sum
GW	65	56	4	125
LW	0	0	9	9
RW	45	0	0	45
EW	8	0	0	8
sum	118	56	13	187

S(4,2,0)	arrive at the curb side			
start from the curb side	G	CT	R	sum
GW	52	17	2	71
LW	0	0	18	18
RW	23	0	0	23
EW	13	0	0	13
sum	88	17	20	125

S(4,3,0)	arrive at the curb side			
start from the curb side	G	CT	R	sum
GW	72	16	0	88
LW	0	0	35	35
RW	37	0	0	37
EW	7	0	0	7
sum	116	16	35	167

S(4,3,1)	arrive at the curb side			
start from the curb side	G	CT	R	sum
GW	52	17	2	71
LW	0	0	18	18
RW	23	0	0	23
EW	13	0	0	13
sum	88	17	20	125

S(4,3,0)	arrive at the curb side			
start from the curb side	G	CT	R	sum
GW	72	16	0	88
LW	0	0	35	35
RW	37	0	0	37
EW	7	0	0	7
sum	116	16	35	167

S(4,3,1) far side to near side	arrive at the curb side			
start from the curb side	**G**	**CT**	**R**	sum
GW	27	0	24	51
LW	0	3	0	3
RW	0	0	38	38
EW	0	0	2	2
sum	27	3	64	94

S(4,3,1) far side to near side	arrive at the refuge island			
start from the refuge island	**G**	**CT**	**R**	sum
GW	14	0	16	30
LW	0	5	0	5
RW	0	0	58	58
EW	0	0	1	1
sum	14	5	75	94

S(4,3,1) near side to far side	arrive at the curb side			
start from the curb side	G	CT	R	sum
GW	20		5	25
LW		6		6
RW			45	45
EW				0
sum	20	6	50	76

S(4,3,1) near side to far side	arrive at the refuge island			
start from the refuge island	G	CT	R	sum
GW	52	0	0	52
LW	0	14	0	14
RW	0	0	10	10
EW	0	0	0	0
sum	52	14	10	76

C.3.2 Interactions and conflicts

S(2,2,0)-1	level 0	level1	level 2a	level 2b	level 3
GW	31	185	-	-	-
LW	-	-	65	6	0
RW	-	-	248	8	1
EW	-	-	22	0	0

S(2,2,0)-2 at near side	level 0	level1	level 2a	level 2b	level 3
GW	0	26	-	-	-
LW	-	-	0	0	0
RW	-	-	161	0	0
EW	-	-	0	0	0

S(2,2,0)-2 at far side	level 0	level1	level 2a	level 2b	level 3
GW	29	6	-	-	-
LW	-	-	0	0	0
RW	-	-	13	1	0
EW	-	-	0	0	0

S(2,2,0)-3 at near side	level 0	level1	level 2a	level 2b	level 3
GW	3	21	0	0	0
LW	-	-	3	4	0
RW	-	-	2	0	0
EW	-	-	0	3	0

S(2,2,0)-3 at far side	level 0	level1	level 2a	level 2b	level 3
GW	14	55	-	-	-
LW	-	-	17	2	0
RW	-	-	0	0	0
EW	-	-	0	0	0

S(3,2,0) at near side	level 0	level1	level 2a	level 2b	level 3
GW	4	30	-	-	-
LW	-	-	0	0	0
RW	-	-	44	0	0
EW	-	-	0	0	0

S(3,2,0) at far side	level 0	level1	level 2a	level 2b	level 3
GW	0	29	-	-	-
LW	-	-	4	0	0
RW	-	-	38	4	1
EW	-	-	0	0	0

S(4,2,0) at near side	level 0	level1	level 2a	level 2b	level 3
GW	0	0	-	-	-
LW	-	-	5	1	0
RW	-	-	2	3	1
EW	-	-	0	0	0

S(4,2,0) at far side	level 0	level1	level 2a	level 2b	level 3
GW	0	0	-	-	-
LW	-	-	0	0	0
RW	-	-	6	0	0
EW	-	-	0	0	0

S(4,3,0) at near side	level 0	level1	level 2a	level 2b	level 3
GW	0	0	-	-	-
LW	-	-	0	0	0
RW	-	-	53	4	0
EW	-	-	0	0	0

S(4,3,0) at far side	level 0	level1	level 2a	level 2b	level 3
GW	0	0	-	-	-
LW	-	-	0	10	0
RW	-	-	112	2	0
EW	-	-	0	0	0

S(4,3,1) at near side	level 0	level1	level 2a	level 2b	level 3
GW	6	73	-	-	-
LW	-	-	4	0	0
RW	-	-	63	2	2
EW	-	-	0	0	0

S(4,3,1) at far side	level 0	level1	level 2a	level 2b	level 3
GW	2	0	-	-	-
LW	-	-	0	0	0
RW	-	-	111	4	0
EW	-	-	0	0	0

D Model calculation to evaluate effect of measures

D.1 Model calculation related to refuge islands

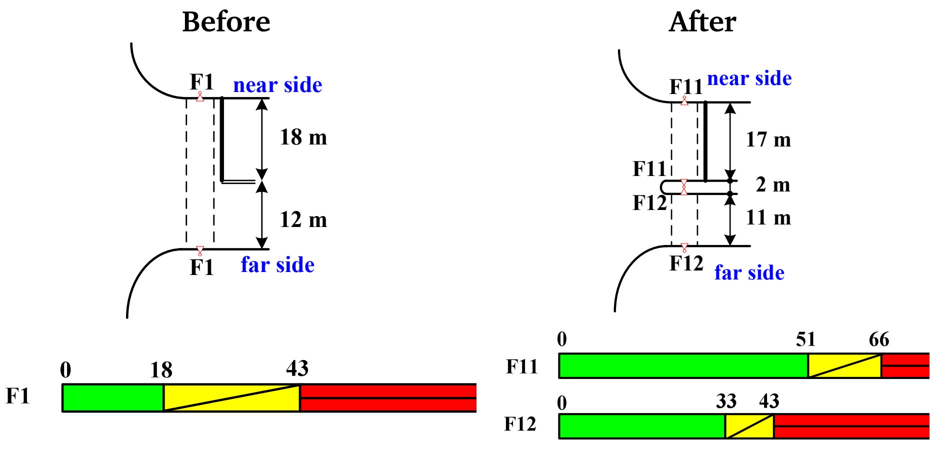


Figure 11: Sketch of the intersection and signal program

Table 12: Calculation table for MOEs

	Before(without refuge island)		After (with refuge island)	
	entrance	exit	entrance	exit
g (s)	18	18	51	33
fg(s)	25	25	15	10
r(s)	69	69	46	69
C(s)	112	112	112	112
q_5+q_6 (veh/h)	525	525	525	525
n_i(entrance)	3	3	3	3
q_{11}(veh/h)	380	380	380	380
q3(veh/h)	190	190	190	190
n_i(exit)	2	2	2	2
L (m)	30	30	17	11
q_{ped}	150	150	150	150
$q_{ped\text{-}R}$	0.78	0.78	0.60	0.70
N_R (p)	118	118	90	105
P_{RW+EW}	66%	44%	35%	52%
N_{RW}(p)	78	52	31	59
$N_{GW\text{-}R}$(p)	40	66	58	45
N_{GW}(p)	72	98	119	91
p_{GW}	48%	65%	79%	60%
1- p_{GW}	52%	35%	21%	40%
$n_{int\text{-}RW}$	125	84	31	63

D.2 Modal calculation related to left turning phasing

The intersection is located in a commercial area, intersected by a main street (west-east) and a minor street(south-north), the lane arrangement and traffic volume are marked in Figure 11.

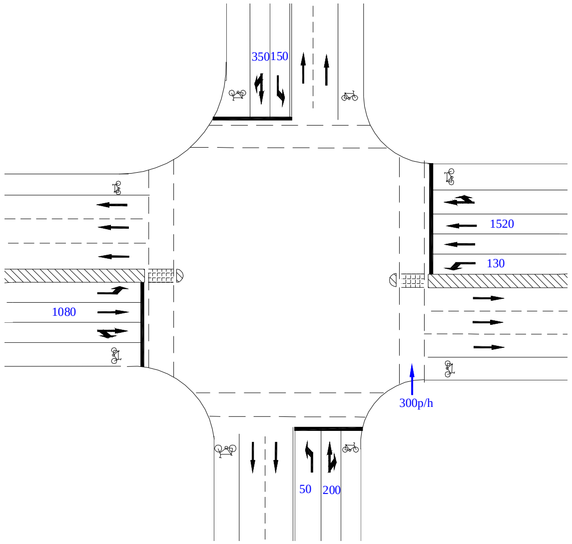


Figure 12: Sketch of the intersection for case study

Step 1: Calculate signal programs under permissive, protected and permissive/protected left-turn phasing based on the current traffic flow using methods recommended on RilSA. Signal program must satisfy the requirement of pedestrian minimum green time, pedestrian clearance time and minimum green time for vehicle traffic.

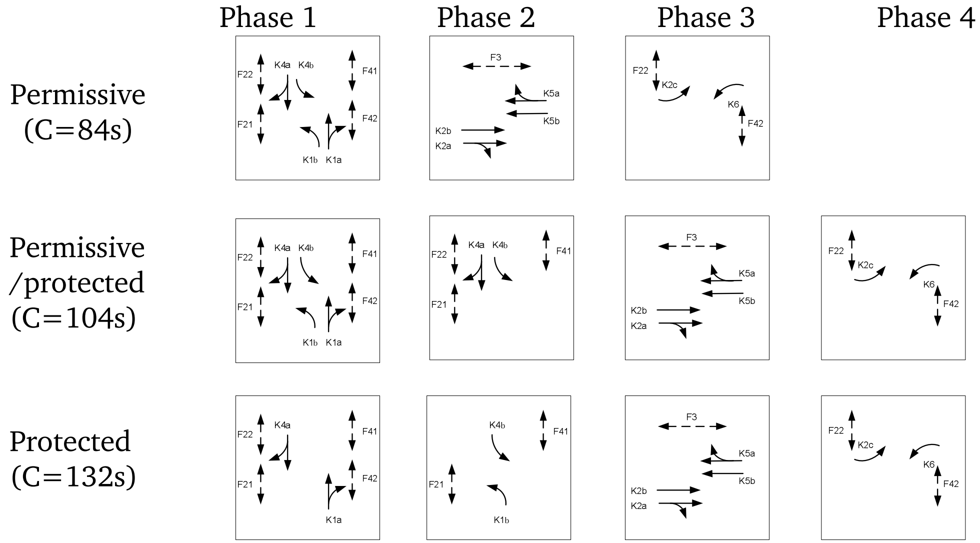


Figure 12: Signal phasing

Step 2: Calculate and compare measures of effectiveness under three left-turn phasing.

Table 13: Comparison of measures of effectiveness under current traffic flow

measures of effectiveness	permissive	permissive /protected	protected
Number of GW (p/h)	226	193	194
Number of RW (p/h)	74	107	106
Number of interactions of GW	119	15	0
Number of interactions of RW	119	186	184
Average delay of GW (s)	20.1	27.7	29.8
Saturation degree of left-turn lane	0.41	0.79	0.85

Under the current traffic flow, permissive/ protected and protected left-turn phasing has nearly no differences regarding to pedestrian non-compliance and interactions, but permissive left-turn phasing provides safer situations for pedestrians, since 30% fewer pedestrians crossing on RED, 35% less interactions of RW. Though more pedestrians take interactions with permissive left-turn vehicles, the average delay of GW is still about 30% lower than the other two, because of much shorter waiting time for GREEN.

Step 3: Keep other traffic volume fixed, change following traffic volumes: (1) Left-turn volume is changed between 50veh/h ~350veh/h;(2) Pedestrian volume is changed between 150 ped /h ~600ped/h. Recalculate signal programs and compare performance indices to find out more general results of applying different left-turn phasing.